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Waterways Experiment
Station

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June 1998

Expedient Road Construction Over Sands Using Lightweight Mats

by Steve L. Webster, Jeb S. Tingle

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by Steve L. Webster, Jeb S. Tingle

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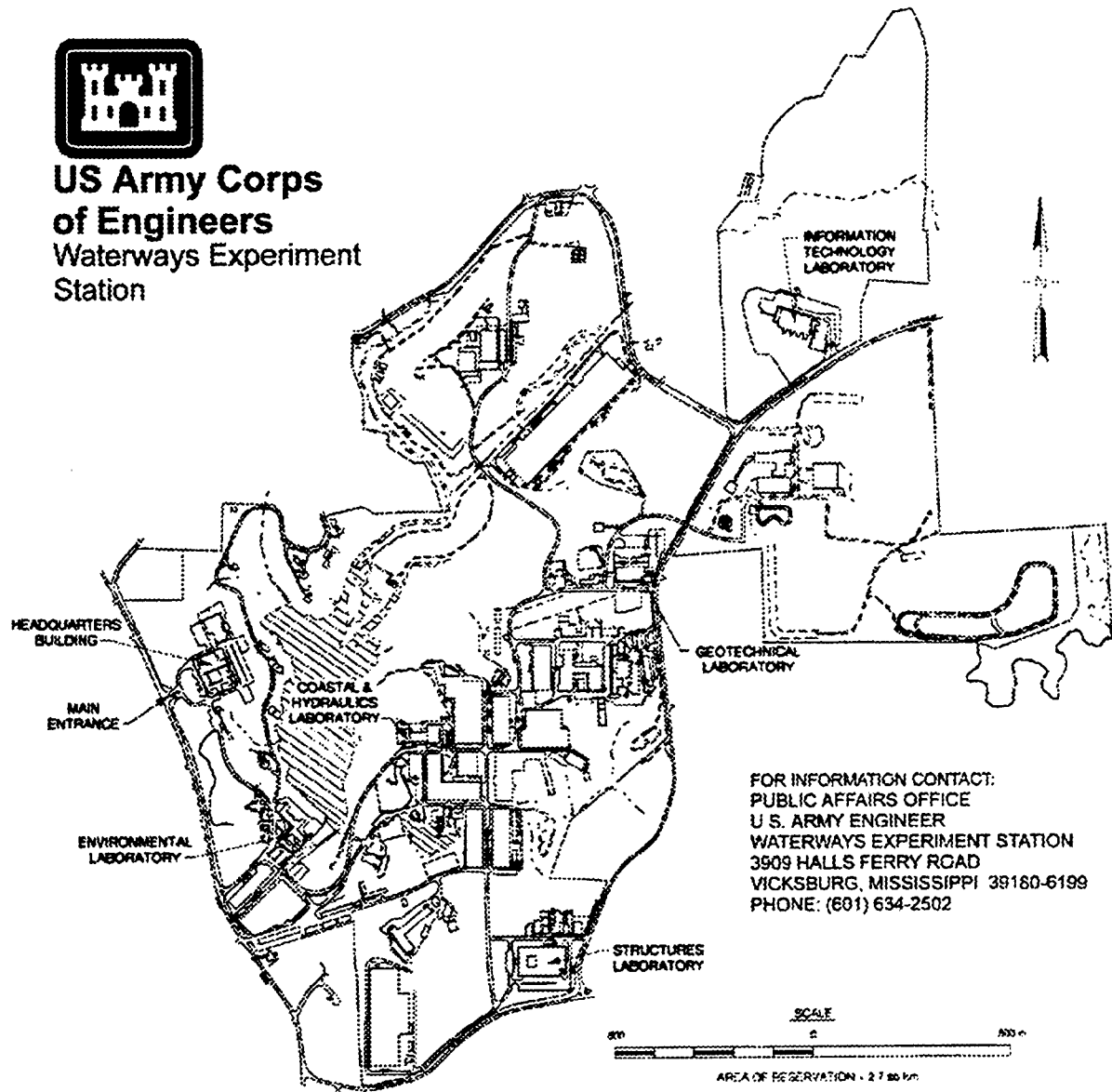
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Preface

The investigation described in this report was sponsored by Headquarters, U.S. Army Corps of Engineers, under Work Unit AT40-MM-005, "Advanced Materials for Construction of Contingency Pavement." The Army technical monitor was Mr. Robert A. Harris (ATSE-CTE). The numerical data were measured and is presented in non-SI units for the sponsor. A conversion factors table is provided to convert the non-SI units to SI units.

This publication was prepared by the U.S. Army Engineer Waterways Experiment Station (WES) based upon experiments conducted during the period 1 June through 5 September 1997. Staff members actively engaged in the planning and implementation of the investigation were Messrs. Steve L. Webster, Jeb S. Tingle, Thomas P. Williams, and R. Bradley, Airfields and Pavements Division (APD), Geotechnical Laboratory (GL). Technical assistance was also provided by Messrs. C.W. Pritchard, Dennis J. Beausoliel, George Walker, and Charles Wilson, Directorate of Public Works, WES. This publication was prepared by Messrs. Webster and Tingle under the general supervision of Dr. W. F. Marcuson III, Director, GL, and under the direct supervision of Dr. David W. Pittman, Chief, APD, and Dr. A. J. Bush III, Chief, Technology Application Branch, APD.

Director of WES during the conduct of the investigation and preparation of this report was Dr. Robert W. Whalin. Commander was COL Robin R. Cababa, EN.

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Executive Summary

The field experiment evaluating the lightweight mats presented in this report was conducted in the Hangar 4 Test Facility during the period June through September 1997 by the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Traffic was applied to the lightweight mats using a 5-ton military truck loaded to a gross vehicle weight of 41,600 lb. The field traffic experiment was performed to evaluate the potential of each mat as an expedient road surfacing when placed over sand subgrades and trafficked with wheeled military vehicles. A summary of each material investigated and its performance is presented in this report. An analysis of the field data was conducted to determine the potential of these expedient surfacings under actual loading conditions.

The results of the field experiment and visual observations revealed the following:

- a. The control experiment item with no mat surfacing exhibited ruts in excess of 8 in. after only 25 passes of the traffic vehicle.
- b. Both plastic mesh mats (unreinforced and reinforced) performed poorly during the field experiment. The unreinforced plastic mesh mat and the reinforced plastic mesh mat developed average rut depths of 3.3 in. and 2.2 in., respectively, after only 20 passes of the traffic vehicle. These materials sustained higher traffic levels when buried in 2 in. of sand; however, the ride quality of the traffic vehicle over these areas was extremely poor.
- c. The plastic hexagonal mat and the fiberglass-reinforced mat performed adequately. The plastic hexagonal mat and the fiberglass-reinforced mat developed average rut depths of 2.8 in. and 1.8 in., respectively, after 5,000 passes of the traffic vehicle.
- d. The aluminum hexagonal mat performed well during the traffic testing. Average rut depths of 1.1 in. were noted after 5,000 passes of the traffic vehicle.

- e. The performance of the plastic hexagonal mat, the fiberglass-reinforced mat, and the aluminum hexagonal mat indicated that they will perform adequately as expedient road surfacings when placed over sand subgrades and trafficked with military trucks.

Detailed material information is provided in Chapter 2 of this report. Chapter 3 of this report presents the field experiments and their results. Recommendations are shown in Chapter 4. Tables are incorporated within the individual chapters. Figures and photos follow the report text.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet (cu ft)	0.02832	cubic meters (m ³)
degrees (angle)	0.01745329	radians
feet (ft)	0.3048	meters (m)
gallons (gal)	3.785	liters (L)
gallons per square yard (gsy)	4.5273149	liters per square meter (L/m ²)
inches (in.)	0.0254	meters (m)
kips, (1,000 lb)	0.4535924	1,000 kilograms (1,000 kg)
pounds (mass) (lb)	0.4535924	kilograms (kg)
pounds (force) (lb)	4.448	newtons (N)
tons (mass) (tons)	8.896	kilonewtons (kN)
pounds (force) per square inch (psi)	6.894757x10 ⁻³	megapascals (MPa)
pounds (force) per square foot (psf)	47.88026	pascals (Pa)
pounds (mass) per cubic foot (pcf)	0.157	kilonewtons per cubic meter (kN/m ³)
square inches (sq in.)	6.4516x10 ⁻⁴	square meters (m ²)
square feet (sq ft)	0.0929	square meters (m ²)
square yards (sq yd)	0.8361	square meters (m ²)

1 Introduction

Background

In many areas of the world, the in situ soil does not possess adequate strength to support aircraft or ground vehicle operations. A structural medium is required to support operations over soft soils. The structural medium can consist of a structural mat, a layer of stronger material over the weak layer, or a combination of a strong soil layer and a mat surfacing. This investigation concerns the use of lightweight mats as a structural medium for roadway surfacings. Existing mats can be divided into two major categories depending upon their application: airfield mats and roadway mats.

Airfield mats

Current aluminum and steel mats used by the military were developed for constructing expedient airfields. These airfield mats were designed to support the higher gross loads and tire pressures associated with aircraft. M8A1 is classified as a light-duty steel mat; however, the mat fails to meet the light-duty requirements to withstand 1,000 coverages of a 30,000-lb, single-wheel load (100-psi tire pressure) on a 4-California Bearing Ratio (CBR) subgrade. Three medium-duty aluminum mats (XM18, M19, and AM2) were developed to withstand 1,000 coverages of a 25,000-lb single-wheel load (250-psi tire pressure) on a 4-CBR subgrade. A heavy-duty truss web aluminum mat was developed to withstand 1,000 coverages of a 50,000-lb, single-wheel load (250-psi tire pressure) on a 4-CBR subgrade.

These mats range in weight from 7.5 lb per sq ft (psf) for the light-duty M8A1 steel mat to 4.25 psf for the medium-duty M19 aluminum mat. The last known military purchase of the M8A1 mat was 1968, and the greatest use of the medium-duty mats was during the Vietnam war. The heavy-duty truss web mat has never been purchased for military use.

Roadway mats

The military's strategic shift from a forward-deployed force to a CONTinental United States (CONUS) -based force resulted in the requirement for increased force projection capabilities. The important role of

logistics-over-the-shore (LOTS) operations in future military operations has created a need for roadway matting systems for use over sand beaches. The following three types of mat were used in the 1991 Joint Logistics-Over-The-Shore III (JLOTS) exercises conducted at Fort Story, Virginia, and the 1993 JLOTS III exercises conducted at Camp Lejeune, North Carolina.

- a. **Mo-Mat.** Mo-Mat consists of semirigid panels of fiberglass-reinforced resin material which is rolled out, bolted together, and anchored in place to form temporary roadways and various size parking/storage pads. The panel material is 0.085 in. thick and molded into a waffle-like pattern that is 0.625 in. thick. Mo-Mat panels are 12 ft, 2 in. wide by 48 ft, 6 in. long and weigh 1.06 psf. Mo-Mat is shipped in rolls and performs well as a roadway for rubber-tired vehicles. It is suitable for applications that require frequent deployment and retrieval such as at bare beach landing sites where it is used as a connecting roadway between lighterage and the roadway network. Rolls of Mo-Mat are bulky, but its transportability is good. The 1984 cost of Mo-Mat was \$14.00 per square foot (Department of Defense 1985). Mo-Mat is no longer available on the commercial market.
- b. **M8A1 steel mat.** This light-duty airfield mat works well for large turning area pads and straight roadway sections. However, it requires significant maintenance when used in curved roadway sections. Transportability is poor, primarily due to the weight of the mat.
- c. **Uni-Mat.** Uni-Mat is a patented, interlocking mat made from hardwood lumber. Mat panels are 8 ft by 14 ft and weigh approximately 1,400 lb each (12.5 psf). Uni-Mat provides heavy-duty roadways over sands or wet soils having a CBR strength of 0.5 or greater. Uni-Mat also serves well as support pads for crane operations. Uni-Mat roads should always be constructed using two layers of the interlocking mat. If only one layer is used, the road will fail quickly. Uni-Mat is reusable for periods of 3 to 7 years. Only a small crane or fork lift and two or three laborers with pry bars are required for installing the mats. Approximately 100 ft of single-lane roadway can be installed per hour. Transportability is poor because the mat is heavy and bulky.

Only limited supplies of Mo-Mat and M8A1 steel mat exist. Both mats are of very old design and have significant limitations. The poor transportability of Uni-Mat prohibits its use in many military applications. Thus, improved lightweight roadway mats are needed for future LOTS operations and other engineering applications. Lightweight mats would have been useful during base development for "Operation Joint Endeavor" in Bosnia.

Purpose

This report presents the results of field traffic evaluations conducted on new lightweight roadway matting materials that are commercially available or are currently being developed.

Scope

This investigation was limited to field evaluations of lightweight mats placed over a sand subgrade. Traffic was applied using a 5-ton military truck (6 by 6, M923) loaded to a gross vehicle weight of 41,600 lb. The truck tire pressure was 80 psi. A total of 5,000 channelized truck passes were applied over the experimental roadway containing five different mats and one control sand item. The mats evaluated included an unreinforced plastic mesh mat, a reinforced plastic mesh mat, a plastic hexagonal (hex) mat, an aluminum hexagonal (hex) mat, and a fiberglass-reinforced mat.

2 Materials

Sand Subgrade Material

The sand used for the experiment was a local Vicksburg, MS, sand normally used as fine aggregate in concrete. The gradation curve for this sand is shown in Figure 1. The sand was a pit-run washed sand containing approximately 4 percent gravel sizes and no minus No. 200 U.S. standard sieve size material. It was classified as a poorly graded (SP) sand, American Society for Testing and Materials (ASTM) D 2487 (ASTM 1992). Additional material properties for the sand are provided in Table 1 (dry unit weights were determined according to ASTM D 4253 (ASTM 1993)).

Table 1 Sand Properties	
Property	Value
Specific gravity	2.65
Laboratory maximum, dry unit weight	117.7 pcf
Laboratory minimum, dry unit weight	98.2 pcf
Coefficient of uniformity, C_u	2.0
Coefficient of curvature, C_c	1.23
Mean diameter	0.5 mm

Lightweight Mats Evaluated

The mats selected for this study were identified during a recent unpublished study conducted at the U.S. Army Engineer Waterways Experiment Station (WES) to develop a lightweight expedient airfield surfacing capable of withstanding 1,000 coverages of a 30-kip single-wheel load with a 100-psi tire pressure when placed over a 6-CBR subgrade. The mat weight for the original investigation was limited to 3 psf. Results of that study were unsuccessful; however, the research effort did identify the following mats as potential surfacings for expedient road construction when placed over sand subgrades.

Each mat is described below, and the individual mat properties are summarized in Table 2.

Table 2 Mat Properties			
Mat	Panel/Sheet Size	Unit Weight, psf	Unit Cost, per ft²
Fiberglass-reinforced	4 ft x 12 ft	2.92	\$16.32
Plastic hexagonal	2.9 ft ²	2.43	\$6.00
Aluminum hexagonal	2.9 ft ²	7.30	\$61.00
Plastic mesh (unreinforced)	10 ft x 13.8 ft	0.34	\$6.20
Plastic mesh (reinforced)	10 ft x 13.8 ft	0.72	\$20.00

Fiberglass-reinforced mat

This mat was a spinoff of the fiberglass-reinforced mat developed by the U.S. Air Force under its rapid runway repair project. The mat consisted of a polyester resin reinforced with four plies of woven chopped fiberglass. The polyester resin-to-fiberglass ratio was approximately 11:9 by weight. The composite panel was 4-ft by 12-ft by approximately 0.35 in. thick. The weight of a 4 ft by 12 ft panel was approximately 140 lb or 2.92 psf. During installation, the panels were connected to smaller lower joiner panels using threaded bushings. Figure 2 shows the dimensions of the panels used in the experiment. Figure 3 shows the dimensions of the upper threaded bushing and a cross section of the lower bushing that was fabricated in the lower connecting panels. The material cost of the assembled matting was \$16.32 per square foot. The fiberglass-reinforced mat was fabricated by GFI, Inc., Harrison, AR. Photo 1 shows the fiberglass-reinforced mat.

Plastic hexagonal mat

This mat was produced by UmTech-Ecological Technology Company, Inc., Munich, Germany. Mat panels were purchased from the U.S. distributor, Grid Tech, Middletown, RI. These lightweight interlocking mat panels were designed for quick installation to create parking areas and access roadways. The panels are ultraviolet (UV) stable and made from recycled high density polyethylene (HDPE). Each panel weighs 7.05 lb and has a surface area of approximately 2.9 sq ft, resulting in a unit weight of 2.43 psf. The factory recommended maximum wheel load is 13,000 lb per panel when installed over a gravel base. The hexagonal form permits road angles of 30, 60, and 90 deg to be created. The cost of test quantities of the mat was \$6.00 per square foot. Photo 2 shows the plastic hexagonal mat.

Aluminum hexagonal mat

This mat was also produced by UmTech, and mat panels were purchased from Grid Tech. These heavy-duty interlocking panels were designed for quick installation to create both roadbeds and parking areas for heavy construction equipment and heavy vehicle use. The panels can be installed on swampy or hilly terrain. Each aluminum panel weighs 21.17 lb and has a surface area of approximately 2.9 sq ft, resulting in a unit weight of 7.3 psf. The factory recommended maximum wheel load is 28,000 lb per panel when installed over a gravel base, plowed field, or swamp. The hexagonal form permits road angles of 30, 60, and 90 deg to be created. The cost of test quantities of the mat was \$61.00 per square foot. Photo 3 shows the aluminum hexagonal mat.

Plastic mesh mat (unreinforced)

This mobility matting was developed by DESCHAMPS, Nersac, France, and purchased from the U.S. distributor, IN_DEF Services International, Inc., Chantilly, VA. The mat is a heavy-duty reinforced polyester configured in a special proprietary open, cross-weave mesh with a corrugated surface. The material was supplied in rolls, each containing a sheet of mat 13.8 ft wide and 10 ft long. The mat weight was 0.34 psf. The cost of experiment quantities of the mat was \$6.20 per square foot. Photo 4 shows the unreinforced plastic mesh mat.

Plastic mesh mat (reinforced)

This material was the same as the plastic mesh mat described previously, except that it was reinforced with glass fiber/polyester reinforcement rods. The rods were 1 in. in diameter and embedded within the weave across the full width of the mat on 1.5-ft intervals. The material was supplied in rolls, each containing a sheet of mat 13.8 ft wide and 10 ft long. The mat weight was 0.72 psf. The cost of experiment quantities of the mat was \$20.00 per square foot. Photo 5 shows the reinforced plastic mesh mat.

3 Field Experiments

Experiment Design

Description

The field experiment for this investigation was conducted under a shelter in Hangar 4 on the WES reservation. A plan and profile of the field experiment is shown in Figure 4. The experiment was designed to evaluate the load-carrying capabilities of the selected lightweight mats under military truck traffic when installed as roadway sections over a sand subgrade. The 12-ft-wide straight road section was designed for single-lane traffic.

Materials

The subgrade was composed of the concrete sand previously described. A typical gradation curve for the concrete sand material is shown in Figure 1, and a listing of the sand material properties is presented in Table 1. A sand subgrade was selected to simulate a beach environment in order to address (LOTS) issues. The mats used in the experiment are those described in Chapter 2. Each mat is a commercially available product. The fiberglass-reinforced mat was under development at the time of the experiment, and the version evaluated may be considered a prototype. The transportability of the selected mats was also a consideration in their selection.

Construction

General

The experiment was constructed during the period June through August 1997. All work was accomplished by WES personnel using conventional construction equipment to construct the experiment section. The experiment section was divided into six items consisting of a control item and five individual mat surfaced items. The test items were constructed over an 36-in.-thick by 20-ft-wide sand subgrade. The concrete sand subgrade was installed over a firm (CBR>10) CL soil floor in Hangar 4. The subgrade material was leveled and compacted with a D4 bulldozer. A 12-ft-wide straight traffic lane was outlined prior to mat installation. Item 6 of the traffic

lane consisted of the sand control item composed only of the sand subgrade material. Each constructed item was 40 ft long, with the exception of the fiberglass-reinforced item (item 3) which was 64 ft long. The total length of the final traffic lane was 264 ft.

Aluminum hexagonal mat installation

The aluminum hexagonal mat was installed in item 1 of the traffic lane using two to four laborers. Each aluminum panel weighed approximately 21.17 lb and was easily handled by construction personnel. The panels were installed in the pattern illustrated in Figure 5 and required no specialized tools or skills. A small fork lift was used to transport 40-panel crates down the constructed segments of the roadway to supply the laborers during installation. This method provided a continuous supply of panels to the laborers during placement. Photo 6 illustrates the panel installation process. The rate of construction is strictly dependent upon the number of available construction personnel. During construction, a crew of four installed the panels at a rate of 900 ft² of roadway per man-hour.

Plastic hexagonal mat installation

The plastic hexagonal mat was installed in item 2 of the traffic lane also using two to four laborers. Each plastic panel weighed approximately 7.05 lb and was easily handled by construction personnel. The panels were also installed in the pattern illustrated in Figure 5 and required no specialized tools or skills. The plastic panels were directly connected to the aluminum hexagonal panels installed in item 1. A small fork lift was used to transport 40-panel crates down the constructed segments of the roadway in a continuous supply for the laborers during installation. The panel installation process was essentially the same as that of the aluminum hexagonal mats. The rate of construction is strictly dependent upon the number of available construction personnel. During construction, a crew of four installed the panels at a rate of 900 ft² of roadway per man-hour. Photo 7 shows the completed hexagonal mat items.

Fiberglass-reinforced mat installation

The fiberglass-reinforced mat was installed in item 3 of the traffic lane using a minimum of two laborers. The dimensions of the fiberglass-reinforced mat along with the upper and lower bushings are shown in Figures 2 and 3, respectively. Each fiberglass roadway panel weighed approximately 140 lb and was easily handled by two construction personnel. A small fork lift was used to transport 5 to 10 panels across the constructed segments of the roadway to continuously supply the laborers during installation. Two different joiner panels (end and side) were required to connect the larger roadway panels. These joiner panels were aligned on the subgrade immediately prior to the installation of each roadway panel. Each roadway panel was then lowered onto the connecting panels by two laborers. The holes in the roadway panels

were aligned with the holes in the joiner panels below. The upper bushings were then hand-tightened into the lower bushings of the joiner panels through the holes in the upper roadway panels. The upper bushings were then tightened with a hand wrench or an electric impact wrench with the appropriate socket. Photos 8 and 9 illustrate the panel installation process. A wax or grease lubricant should be used to prevent sand from clogging the lower bushings. The edge of the fiberglass-reinforced mat was tucked beneath the ends of the last two rows of the plastic hexagonal mat item. The rate of construction is strictly dependent upon the number of available construction personnel and equipment. During construction, a crew of four installed the panels at a rate of 40 ft² of roadway per man-hour. The slow installation process could be alleviated by redesigning the mat. The redesigned mat will be discussed later and will consist of only one panel size that is connected by a nylon "pop-in" connector.

Plastic mesh mat (reinforced) installation

The reinforced plastic mesh mat was installed in item four of the traffic lane using two to four laborers. Each roll of mat contained four separate panels, each weighing approximately 99.4 lb. The individual panels were separated from the shipping roll and aligned on the roadway. The edge of the first panel was placed beneath the end of the fiberglass-reinforced mat section to ensure a continuous mat structure. The second panel was placed on top of the first, while the ends of both panels were tied together using plastic 3M cable ties. The panels required approximately 20 ties per joint to link the individual mats together. Photo 10 shows two panels being tied together. Once the panels were tied, the top panel was simply flipped onto the roadway. The installation required no specialized tools or skills. The rate of construction is strictly dependent upon the number of available construction personnel. During construction, a crew of four installed the panels at a rate of 100 ft² of roadway per man-hour. Photo 11 shows the completed roadway item.

Plastic mesh mat (unreinforced) installation

The unreinforced plastic mesh mat was installed in item 5 of the traffic lane using two to four laborers. The unreinforced plastic mesh mat was also shipped in a roll of four individual panels, each panel weighing approximately 46.9 lb. The panels were installed in exactly the same manner as the reinforced plastic mesh mat panels previously described. During construction, a crew of four installed the panels at a rate of 100 ft² of roadway per man-hour. Photo 12 shows the completed roadway item.

Behavior of Experimental Section Under Traffic

Application of traffic

Experimental traffic was applied using a M923 5-ton military truck loaded to a gross vehicle weight of 41,600 lb. The individual truck tires were inflated to a 75-psi tire pressure with a contact area of approximately 55.5 in². A total

of 5,000 channelized truck passes was applied to items 1 through 3. Only 25 truck passes were applied to items 4 through 6 due to the rapid deterioration of the originally constructed roadway. Items 1 through 3 could have supported a substantial amount of additional traffic. Experimental traffic was applied by driving the traffic vehicle (approximately 5 to 10 mph) forward over the experimental items, and then backing the length of the traffic lane in the same wheel path. This resulted in two applications of the traffic load or two passes.

Failure criteria

The failure criteria used in the experiment were based primarily on the development of roughness and excessive mat breakage due to subgrade deformation. When the measured rut depth using a 10-ft straightedge exceeded 3 in., the item was considered failed due to rutting. Failure due to mat breakage was defined as sufficient breakage to pose a tire hazard during operations. For the purposes of the experiment, mat breakage in excess of 20 percent indicated item failure. It was determined that normal maintenance procedures would include up to 10 percent mat replacement. These criteria were used to evaluate item performance.

Maintenance

The first item to require maintenance was the control item which rutted to a depth of 8 in. after only 25 passes. Photo 13 illustrates the severe rutting of the sand control item. The sand was then releveled and traffic was discontinued on item 6. Traffic on items 4 and 5 was discontinued due to the rapid development of ruts after only 20 truck passes. The truck drivers complained about severe roughness caused by the transverse reinforcement rods in item 4 that were bridging the ruts. Maintenance was performed on items 4 and 5 by installing approximately 2 in. of sand over the mesh. The sand cover helped to stabilize both mesh mats and allowed additional traffic to be applied. After approximately 1,000 additional truck passes and each additional 1,000 passes, more sand was required in the wheel paths to reduce the accumulated rutting and help reduce the roughness generated by the reinforcement bars in item 4. This maintenance procedure allowed the application of the full 5,000 truck passes on both mesh mat items. Photo 14 shows a typical tear that occurred in the reinforced mesh mat as traffic progressed. The reinforcement bars remained level in the rutted wheel paths which created a rough ride for the truck and a wear point for the mesh. A few of the edge panels in items 1 and 2 tilted up during traffic (Photo 15). One or two truck passes along the outer edges of the traffic lane releveled the mat and no further problems occurred.

Rut depth measurements

Rut depth measurements were recorded at intervals throughout the traffic evaluation period. Measurements were made by placing a 10-ft metal straightedge across the traffic lane at three locations in each item (item quarter points) and measuring the maximum rut depth using a folding ruler. The measured rut

depth included both the permanent deformation and the upheaval within the traffic lane. The average rut depth of each location consisted of the average of the maximum rut depth values from each wheel path. The average of the three locations within each item was recorded as the average rut depth for a given traffic pass level. The cross section data were normalized (each subsequent measurement was subtracted from baseline data taken at zero passes) to clearly identify the damage due to the applied traffic. Figure 6 presents a graphical summary of the rut depth measurements for all experiment items. Table 3 summarizes the detailed rut depth data.

Hexagonal mat, items 1 and 2. Rut depth measurements for item 1 averaged 1.1 in. after 5,000 truck passes. Seating the mat with one or two passes of a vibratory roller prior to traffic would probably have eliminated most of the rutting of the aluminum hexagonal mat. The aluminum hexagonal mat provided excellent structural support for the applied traffic. Rut depth measurements for item 2, the plastic hexagonal mat, averaged 2.8 in. after 5,000 truck passes. The plastic hexagonal mat provided adequate structural support for the applied traffic.

Fiberglass-reinforced mat, item 3. Rut depth measurements for item 3 averaged 1.8 in. after 5,000 truck passes. The mat bridged the actual ruts in the sand subgrade while unloaded. However, during loading the mat flexed to the general shape of the subgrade. The fiberglass-reinforced mat provided adequate structural support for the applied traffic.

Plastic mesh mat, items 4 and 5. Rut depth measurements for item 4, the reinforced plastic mesh mat, averaged 2.2 in. after only 20 truck passes. The unreinforced plastic mesh mat, item 5, experienced rut depths of 3.3 in. after only 20 truck passes. The rapid development of these ruts resulted in the severe roughness of these test items. Both items, 4 and 5, performed poorly and were incapable of structurally supporting minimal truck traffic until the maintenance procedures described earlier were implemented.

Table 3 Rut Depth Summary					
Mat	Rut Depth, in., at Truck Passes				
	20	700	2,500	3,500	5,000
Aluminum hexagonal mat	0.6	1.0	1.1	1.1	1.1
Plastic hexagonal mat	0.7	1.9	2.5	2.5	2.8
Fiberglass-reinforced mat	0.7	1.5	1.8	1.8	1.8
Plastic mesh mat (reinforced)	2.2	—	—	—	—
Plastic mesh mat (unreinforced)	3.3	—	—	—	—
Control sand item: 8-in. ruts after twenty-five 5-ton truck passes.					

Cross section measurements

Surface cross sections were recorded at intervals throughout the traffic period. The cross section measurements were recorded at 1-ft intervals across the traffic lane at the same item quarter point locations where the rut depth measurements were made. These measurements provide an accurate measure of the average maximum permanent surface deformation (ignoring any upheaval). The cross section data were also normalized (each subsequent measurement was subtracted from baseline data taken at zero passes) for analysis purposes. Typical cross section plots for the various items were useful in describing the performance of each mat.

Permanent surface deformation. Figure 7 shows the maximum average permanent surface deformation for each item. The data shown in Figure 7 represents the average maximum permanent surface deformation based on the average of the data taken at the three cross section locations. In general, the permanent surface deformation plot follows the same pattern as the rut depth plot.

Typical cross sections of permanent deformations. Figures 8 through 12 show typical cross sections of permanent deformation for each test item at various pass levels. Figures 8 through 12 indicate that the various items experienced a small degree of upheaval (negative deformation) under the applied traffic. The effects of the channelized traffic is evident by the two distinct wheel paths in each cross section. Distributed traffic would typically result in a more uniform bowl-shaped permanent deformation. Distributing the traffic across the full width of the traffic lane would probably have eliminated much of the upheaval experienced. Figures 11 and 12 show the rutted condition of both the reinforced and unreinforced plastic mesh mat after only 20 passes. The permanent deformation plots show that the aluminum hexagonal mat performed well under the applied traffic. The fiberglass-reinforced mat exhibited the second best performance, followed by the plastic hexagonal mat. Both plastic mesh mats performed poorly.

Post-traffic condition

Photo 16 shows the post-traffic condition of items 4 and 5. Both of these mesh mat items were in poor condition and would not have supported the 5,000 truck passes without the sand maintenance applications described earlier. Photo 13 illustrates the posttest condition of the control item (item 6). Items 1 through 3 provided adequate structural support to withstand the application of 5,000 truck passes. The aluminum hexagonal mat performed well throughout the evaluation period. The only maintenance required consisted of reseating the edge panels by applying two truck passes along the edge of the traffic lane. Additionally, the holes in the top of the aluminum hexagonal panels permitted the sand subgrade to pump onto the surface of the item. The ½-in. layer of pumped sand at traffic completion presented no problem to trafficking the item. Photo 17 illustrates the post-traffic condition of item 1, the aluminum hexagonal mat. The plastic hexagonal mats in item 2 performed adequately with only one panel being damaged. The damaged panel

was located at the interface with item 3, the fiberglass-reinforced mat. Photo 18 shows the post-traffic condition of the plastic hexagonal mat (item 2), and Photo 19 shows the damaged panel. The pumping of the subgrade material was not as evident in item 2 due to the lack of holes in the plastic hexagonal mat. Item 3, the fiberglass-reinforced mat, provided sufficient structure to support the applied traffic. Five of the connecting bolts in the mat came out during the experiment. The threads in the nut plates were stripped out. Photo 20 presents the condition of the fiberglass-reinforced mat section (item 3) following the termination of traffic. The aluminum hexagonal mat, plastic hexagonal mat, and fiberglass-reinforced mat were serviceable and reusable following the completion of the traffic evaluation period.

Analysis and Conclusions

The following analysis and conclusions are based solely on the performance of the selected mats under the test conditions presented in this report. The tests did not include braking or turning traffic conditions.

Construction requirements

All the mats evaluated can be installed directly on a leveled sand subgrade. The rate of installation of the mats evaluated varies by type; however, only two members of construction personnel are absolutely required for all the mats evaluated. The installation of the fiberglass-reinforced mat was particularly meticulous. The process of tightening the threaded bolts in sandy conditions was tedious. A wax or grease lubricant was required to prevent sand from clogging the lower bushings. Redesigning the mat so that there is only one panel size and the use of a "pop-in" nylon connecting pin would greatly improve the installation rate of the mat. Figure 13 presents the proposed design of the fiberglass-reinforced mat panel and the "pop-in" nylon connector. The two hexagonal mats require no specialized tools or skills to install. The current design of the fiberglass-reinforced mat requires a mechanical wrench or power impact wrench to install and a lubricant for the lower bushing. Both plastic mesh mats require some form of connector to connect the panels. 3M cable ties were used in this experiment and performed adequately under the limited traffic.

Material performance

The aluminum hexagonal mat performed well during the evaluation period and experienced very little rutting or deformation. However, the aluminum mat was the most expensive mat evaluated. The plastic hexagonal mat also provided adequate structural support with slightly more rutting and permanent deformation than the fiberglass-reinforced mat. A significant amount of the rutting and deformation of both the aluminum and plastic hexagonal mats could have been reduced by initially seating the mats with a pass or two of a smooth drum vibratory roller. Most of the rutting and permanent surface deformation of these mats was due to the compaction of the sand layer as traffic progressed. The fiberglass-reinforced mat exhibited the second best performance among the mats tested. The mat remained horizontal until

loaded. During loading, the mat flexed to the shape of the subgrade but continued to provide adequate structural support. Both the reinforced and unreinforced plastic mesh mats performed poorly and failed after only limited applications of the traffic vehicle. Table 4 summarizes the performance of each mat under traffic and key information concerning its use.

Table 4 Performance Summary			
Lightweight Mat	Performance	Installation Rate ft²/man-hour	Cost \$/ft²
Aluminum hexagonal	Excellent	900	61.00
Plastic hexagonal	Good	900	6.00
Fiberglass-reinforced	Good	40	16.32
Reinforced plastic mesh	Poor	100	20.00
Unreinforced plastic mesh	Poor	100	6.20

Summary conclusions

The aluminum hexagonal mat performed best; however, the cost does not justify its use except for special circumstances. Applications for use of the aluminum hexagonal mat may include tank crossings, heavy-duty storage facilities, stream crossings, and helipads. The plastic hexagonal mat performed good and was the least expensive mat. The applications of this lightweight mat are unlimited but include expedient road surfaces over sand, temporary parking and storage pads, temporary access/egress roads, and base camp applications. The fiberglass-reinforced mat performed good, but installation was time consuming. The cost of the mat was also significantly greater than that of the plastic hexagonal mat. Redesigning the mat and connecting pin may reduce the mat cost and installation time while providing a more stable surface than the plastic hexagonal mat. The current design can be used for roadway construction over sand subgrades, parking/storage pads, and base camp construction. The reinforced and unreinforced plastic mesh mats are not suitable for roadway construction to support military truck traffic.

4 Recommendations

Field Demonstration

The performance of items 1, 2, and 3 during the traffic evaluation period indicate the potential for excellent field performance when used over sand subgrades. However, the experiments conducted did not include the effects of braking and turning on mat performance. A field demonstration should be conducted to evaluate the performance of the aluminum hexagonal mat, plastic hexagonal mat, and the redesigned fiberglass-reinforced mat under actual field conditions. A field demonstration would also provide valuable insight into the durability of the individual mats and their maintenance requirements. A field demonstration is required to transfer the technology from the laboratory to the warfighter while monitoring mat performance under field conditions.

Additional Research Requirements

Results of this study show great potential for military road applications using the three lightweight mats previously identified. Additional research must be conducted before design guidance for global applications is developed. Future research on lightweight mats should address the following:

- a. Effect of subgrade type (only one subgrade type was studied in this work).
- a. Redesign of the fiberglass-reinforced mat to include only one panel size.
- a. Redesign of the fiberglass-reinforced mat's connection to include the development of a "pop-in" nylon connecting pin.
- a. Effect of tracked vehicles on mat deterioration.
- a. Use of lightweight mats for helipad applications.

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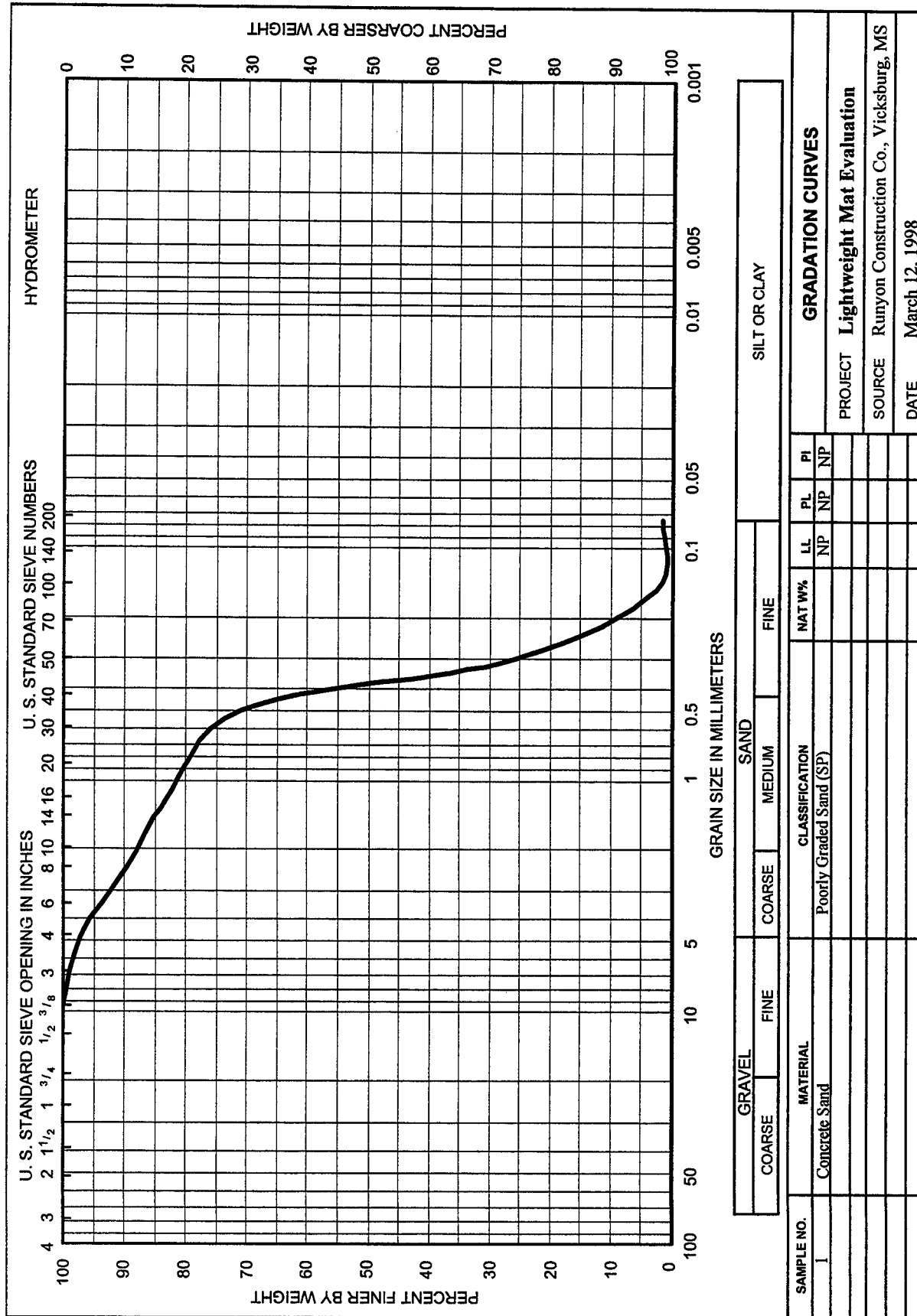


Figure 1. Gradation curve for the concrete sand subgrade material

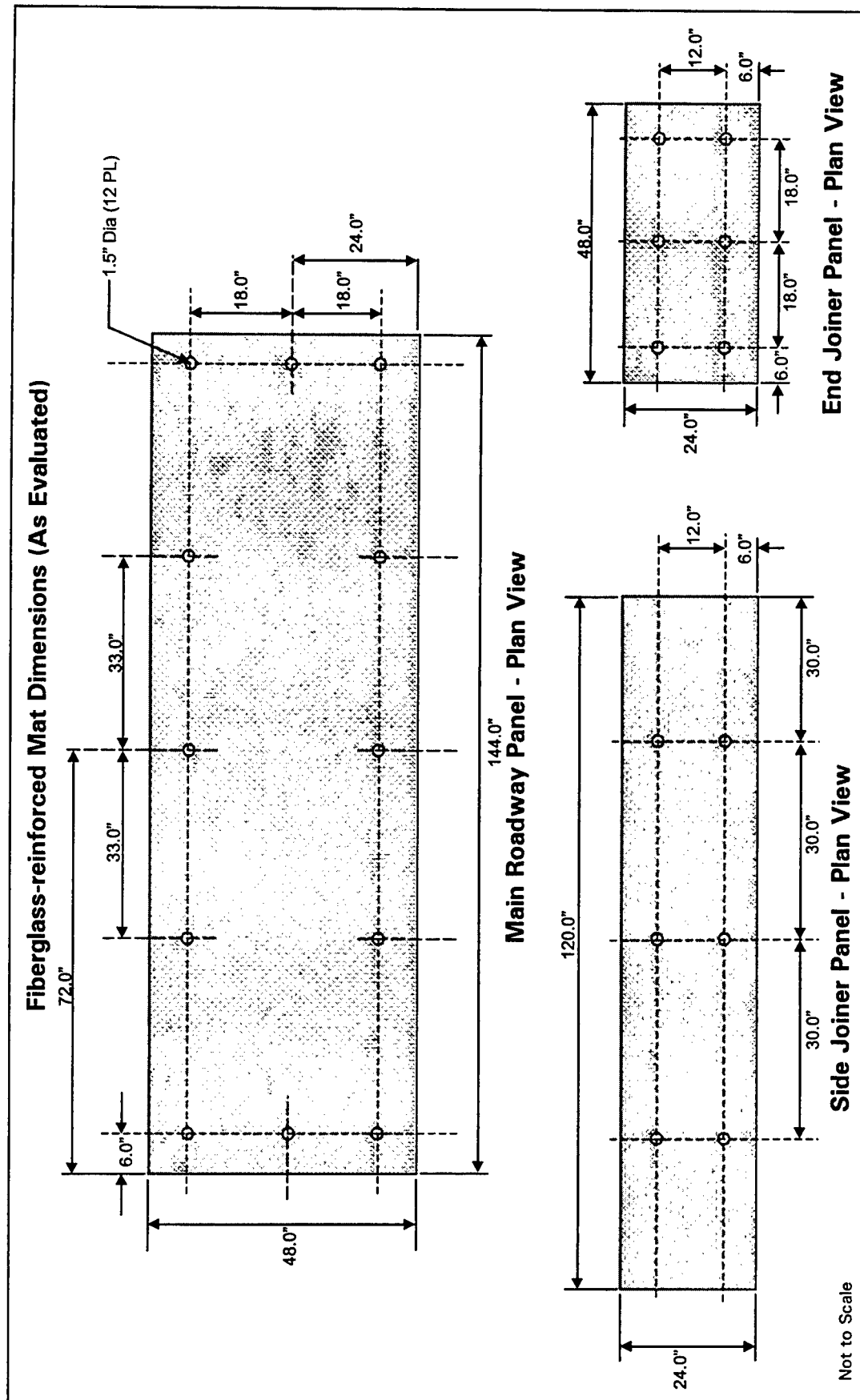
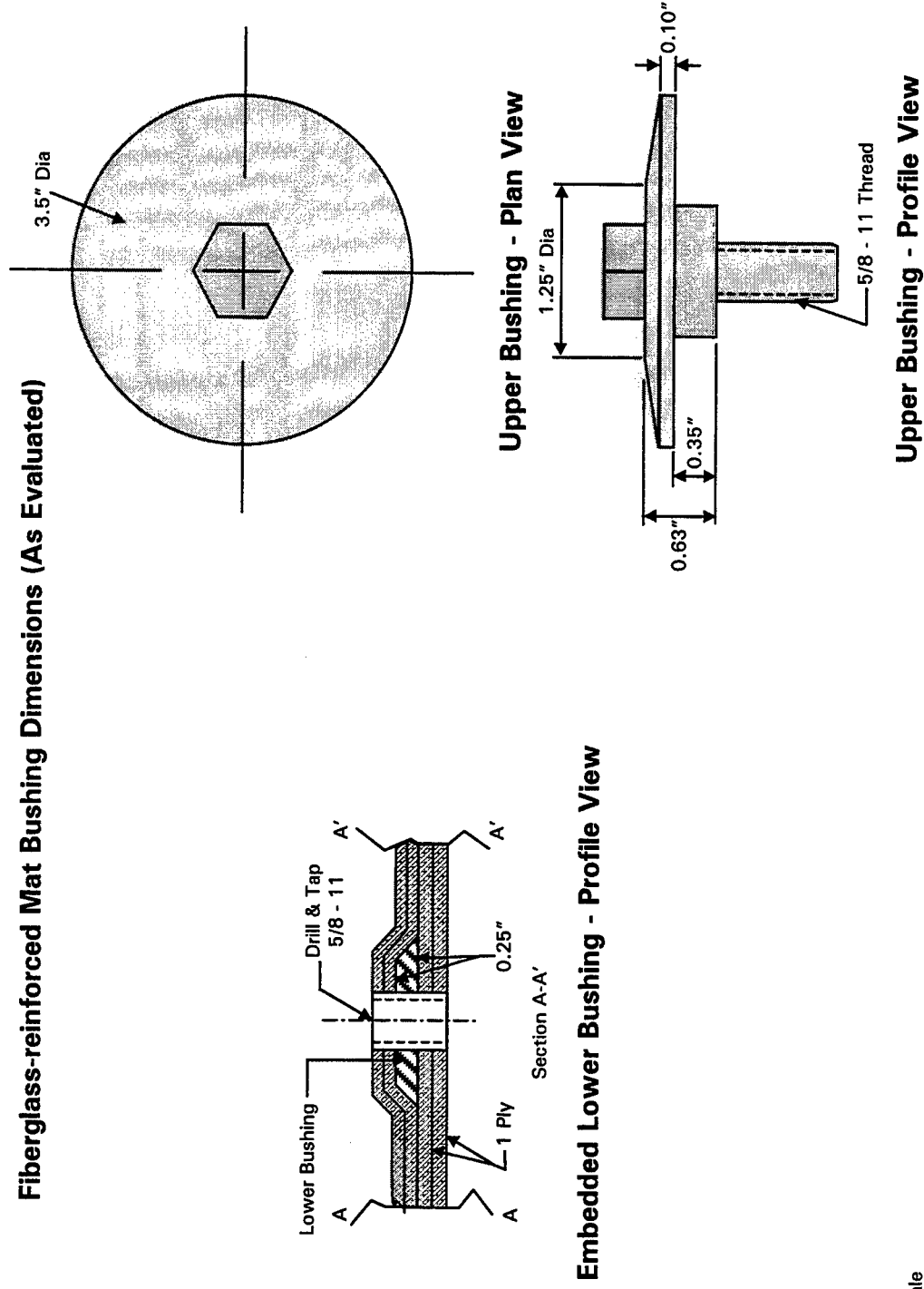


Figure 2. Dimensions of the current (evaluated) fiberglass-reinforced mat

Fiberglass-reinforced Mat Bushing Dimensions (As Evaluated)



Not to Scale

Figure 3. Dimensions of the fiberglass-reinforced mat bushings

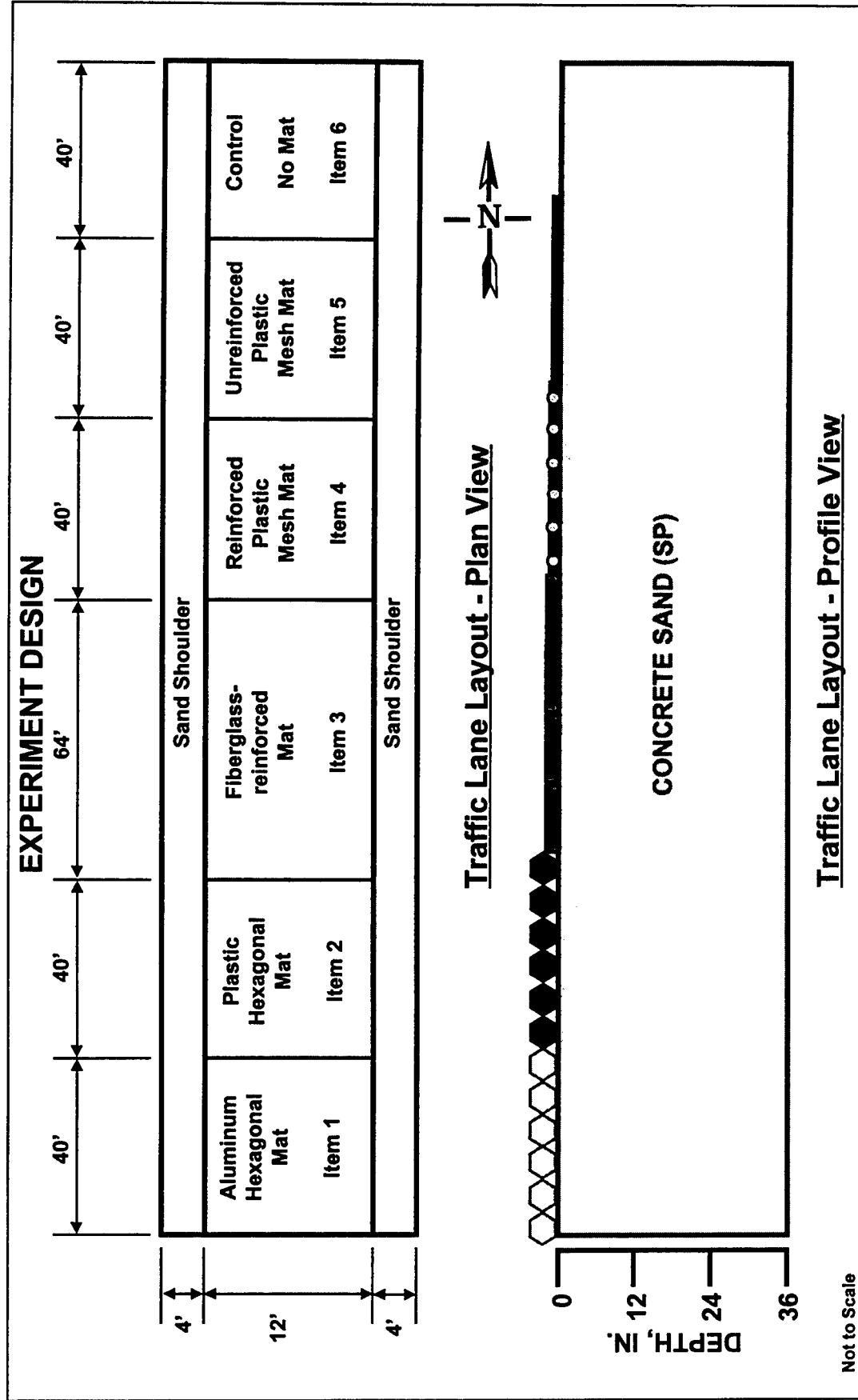
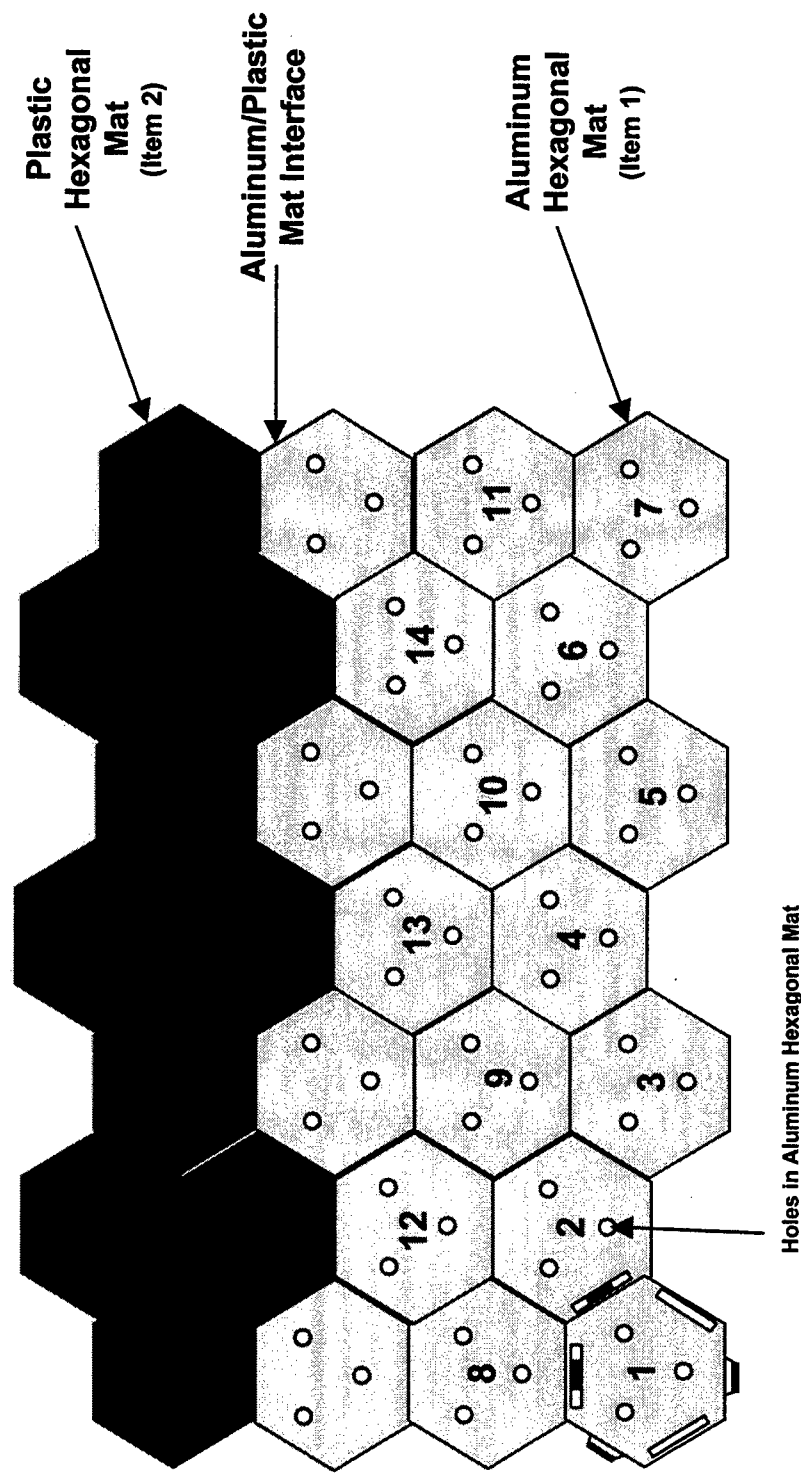


Figure 4. Plan and profile of the field experiment

PLACEMENT PATTERN FOR A HEXAGONAL MAT ROADWAY



Not to Scale

Figure 5. Placement pattern for a hexagonal mat roadway

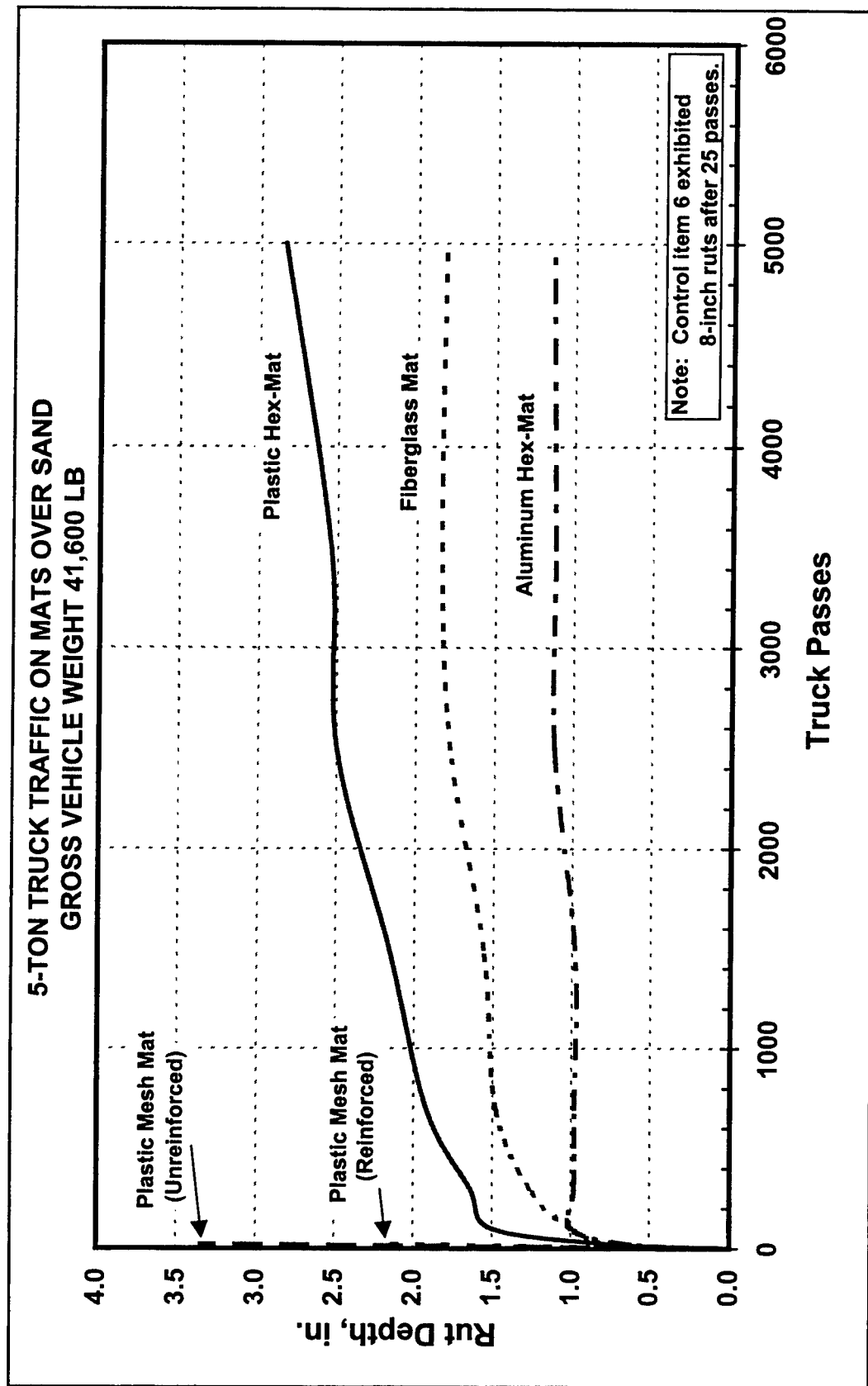


Figure 6. Graphical summary of the rut depth measurements

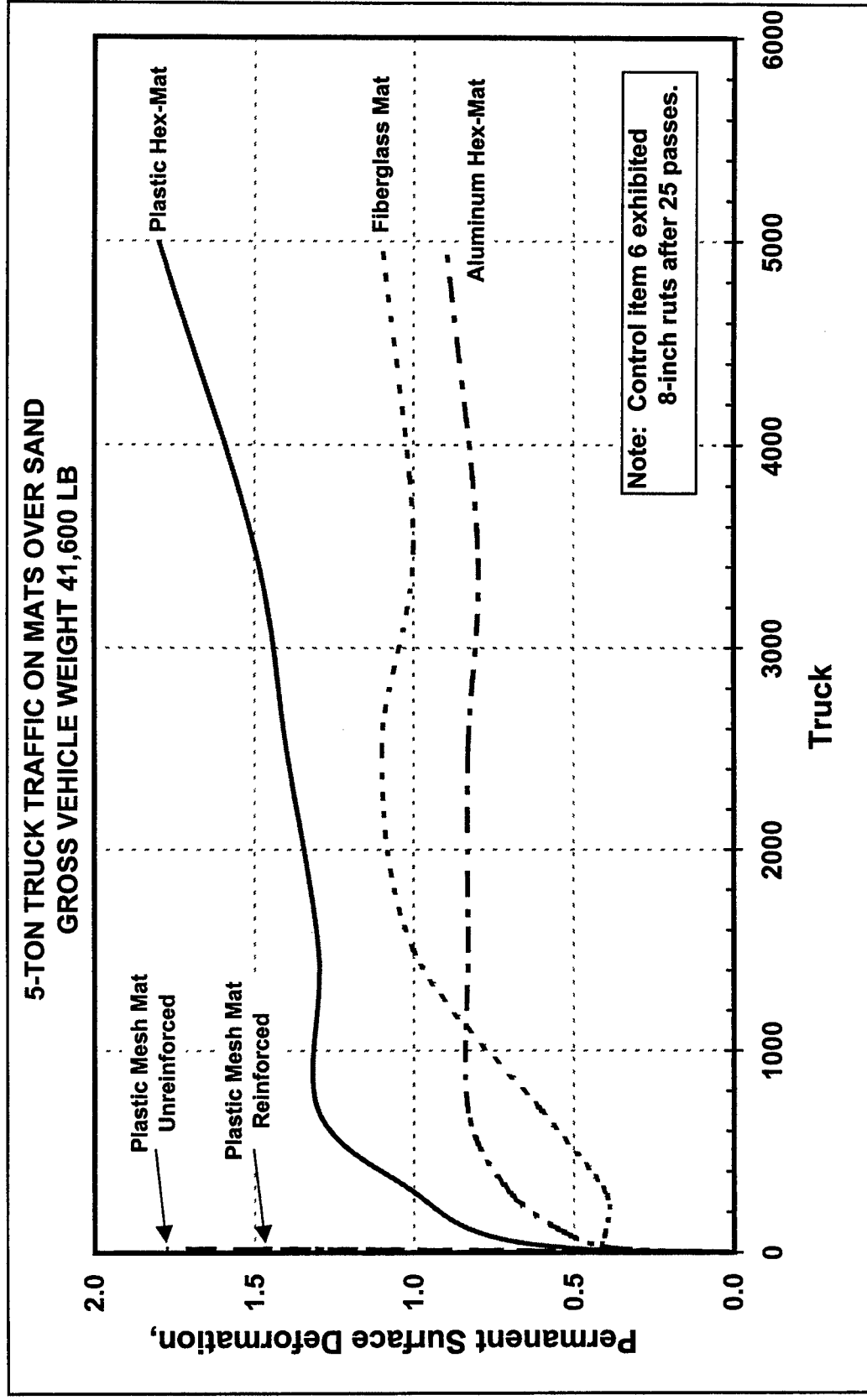


Figure 7. Cumulative permanent surface deformation

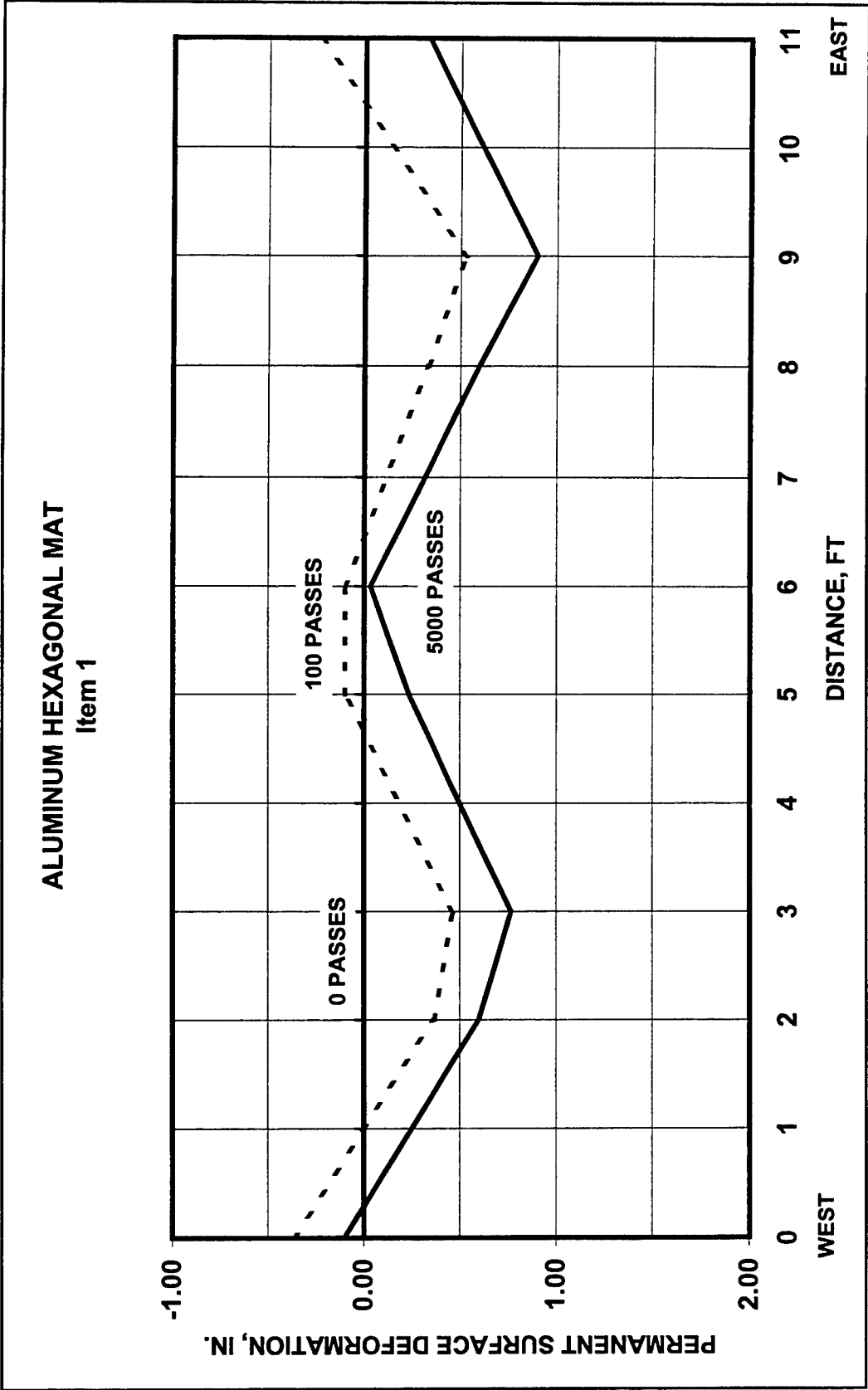


Figure 8. Permanent surface deformation, item 1

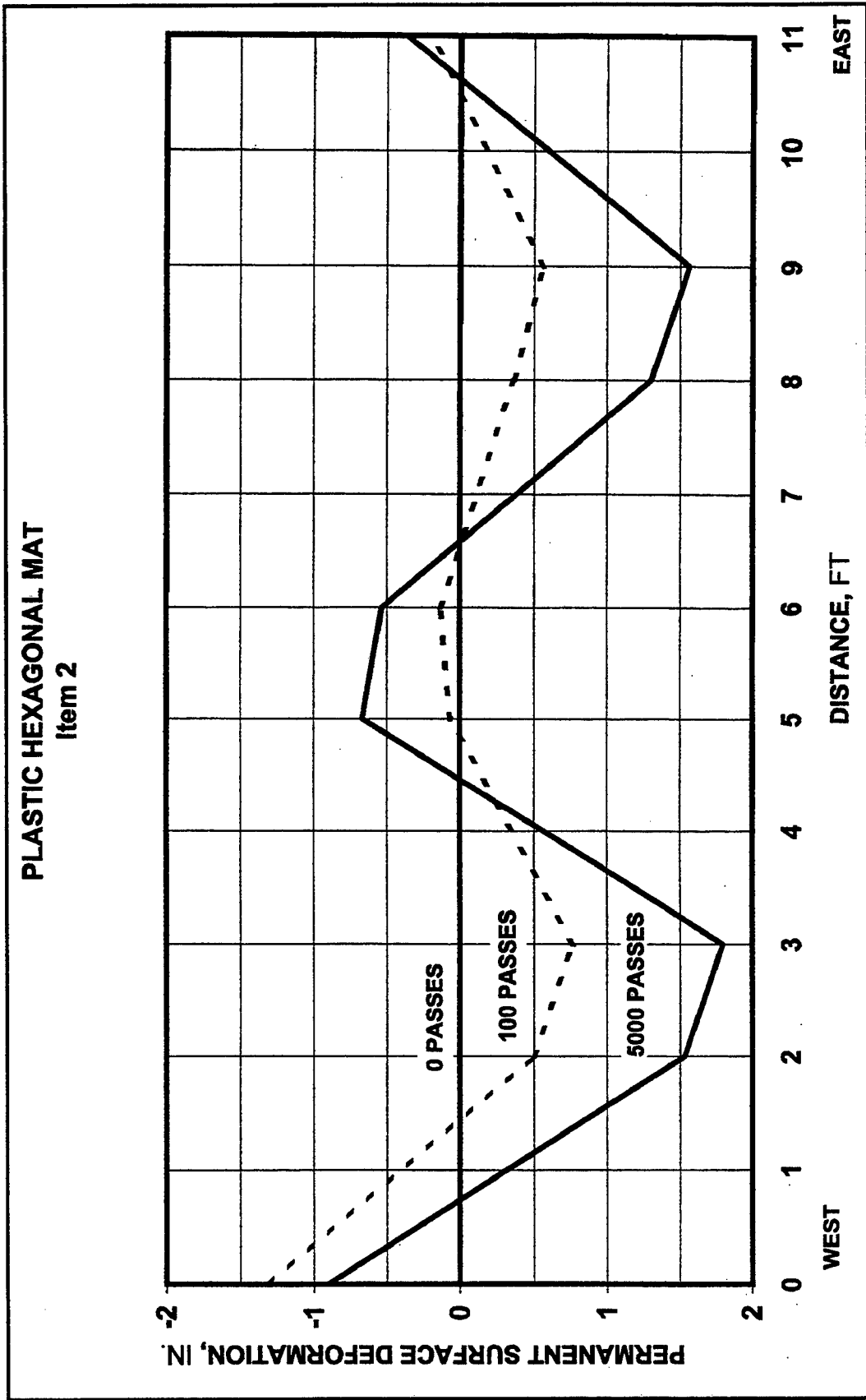


Figure 9. Permanent surface deformation, item 2

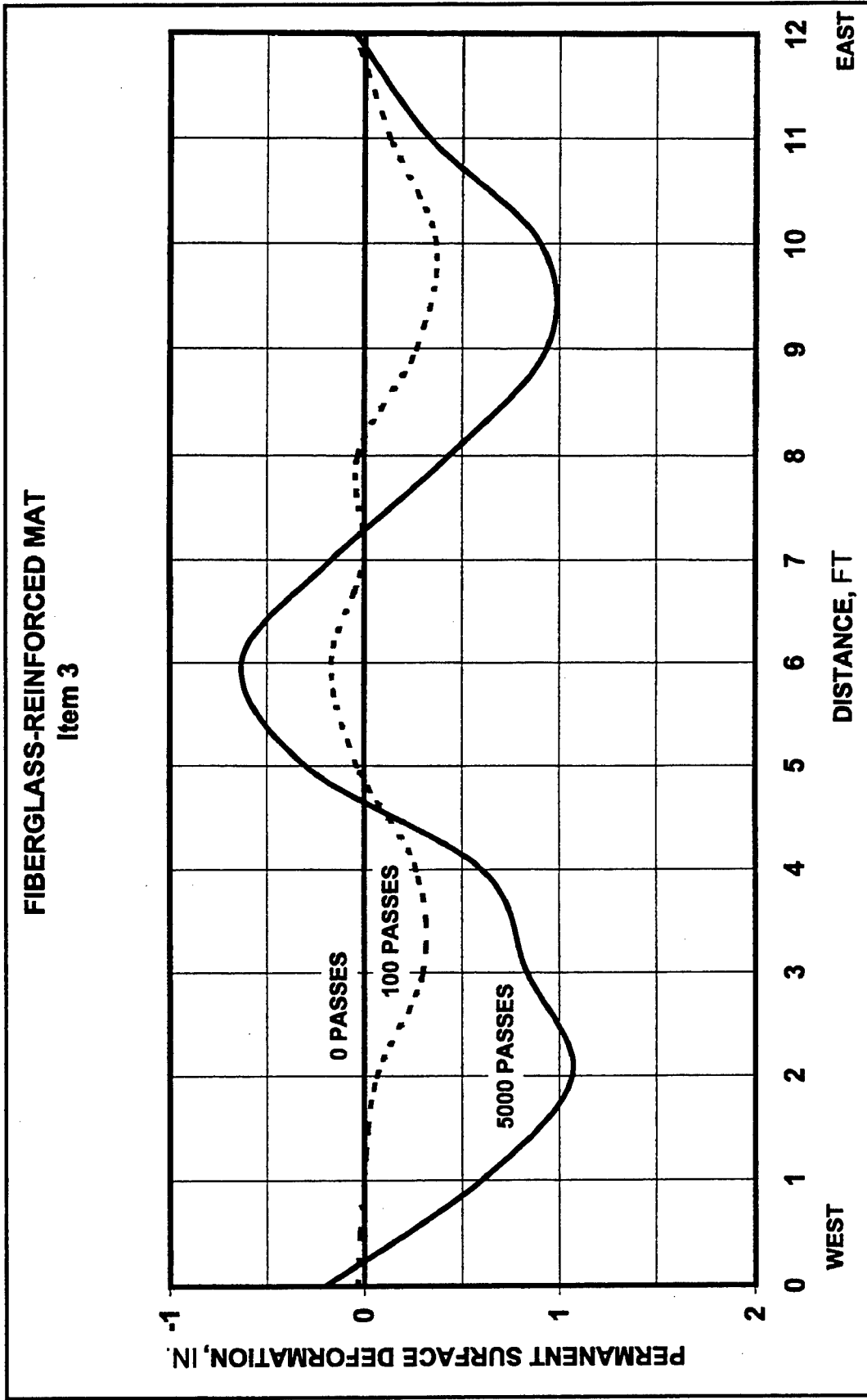


Figure 10. Permanent surface deformation, item 3

REINFORCED PLASTIC MESH MAT

Item 4

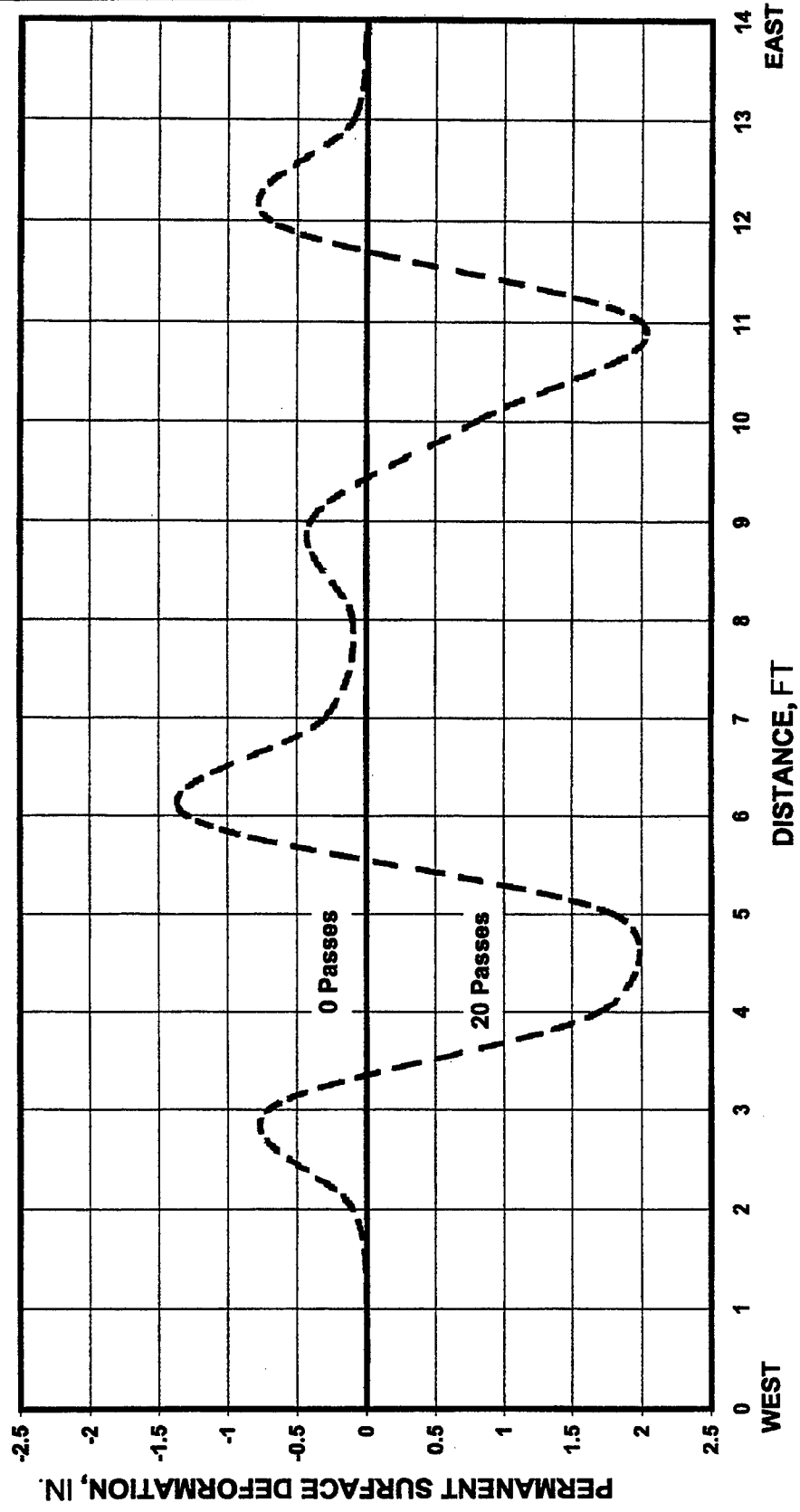


Figure 11. Permanent surface deformation, item 4

UNREINFORCED PLASTIC MESH MAT
Item 5

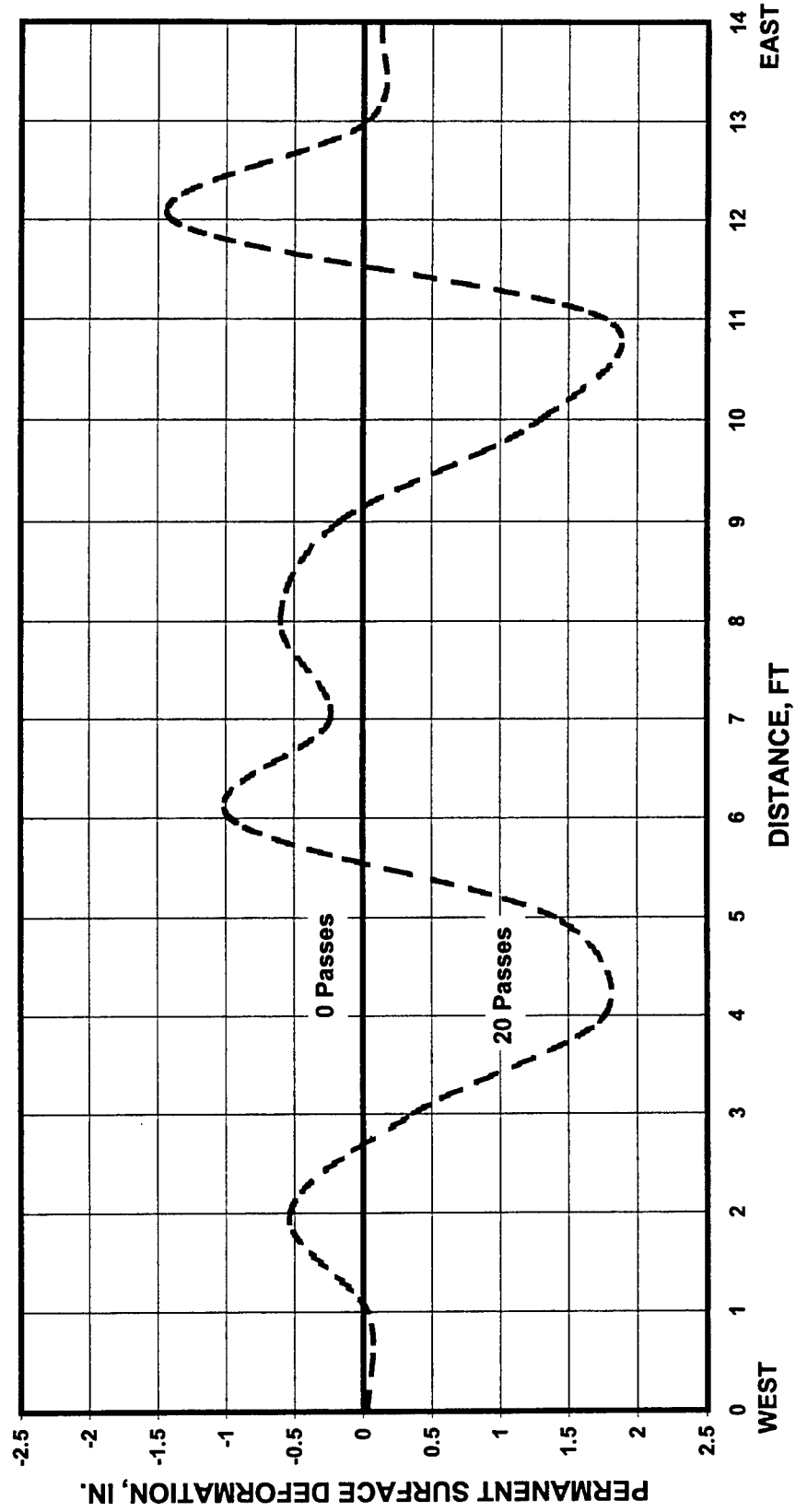


Figure 12. Permanent surface deformation, item 5

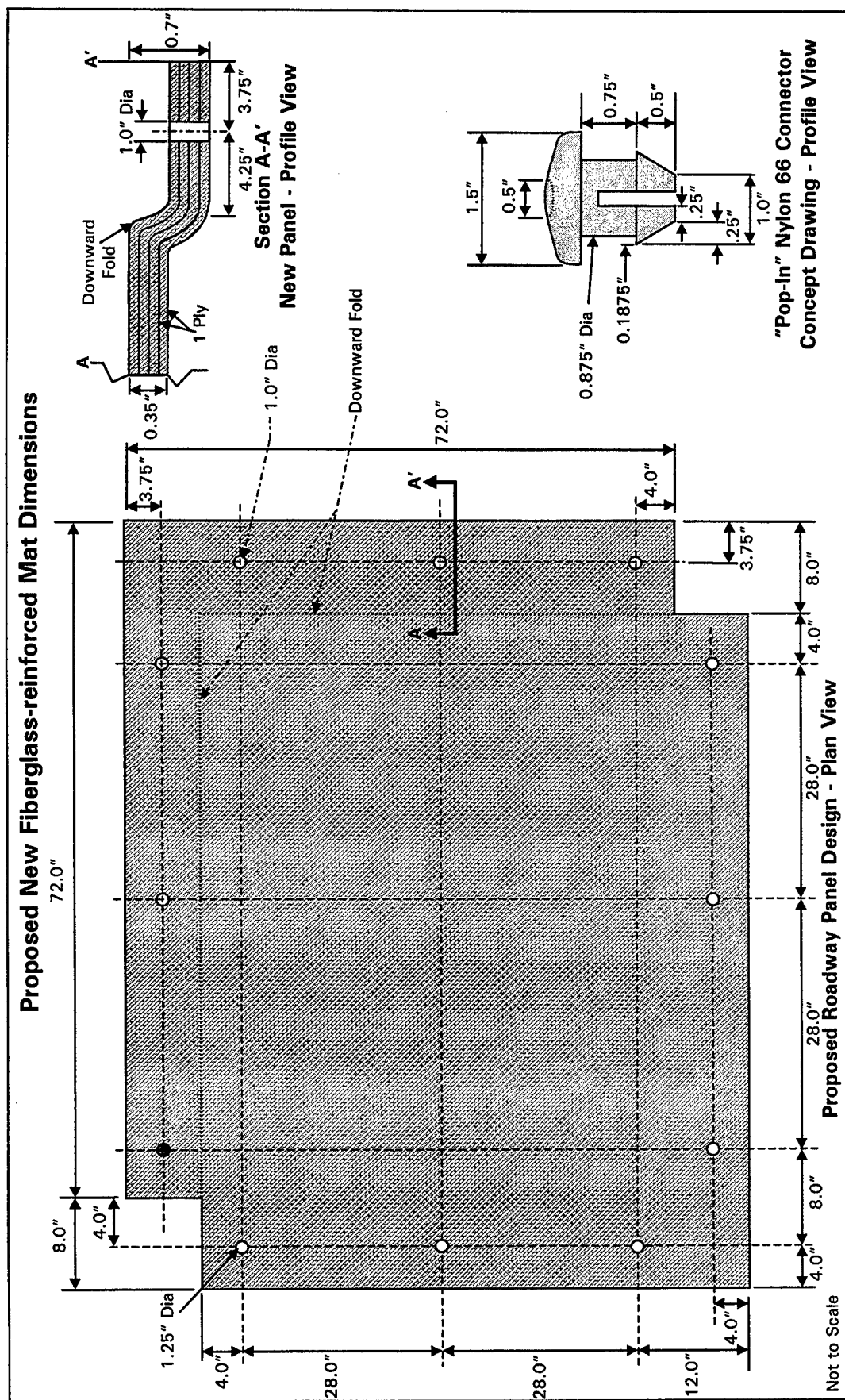


Figure 13. Proposed new fiberglass-reinforced mat and pin

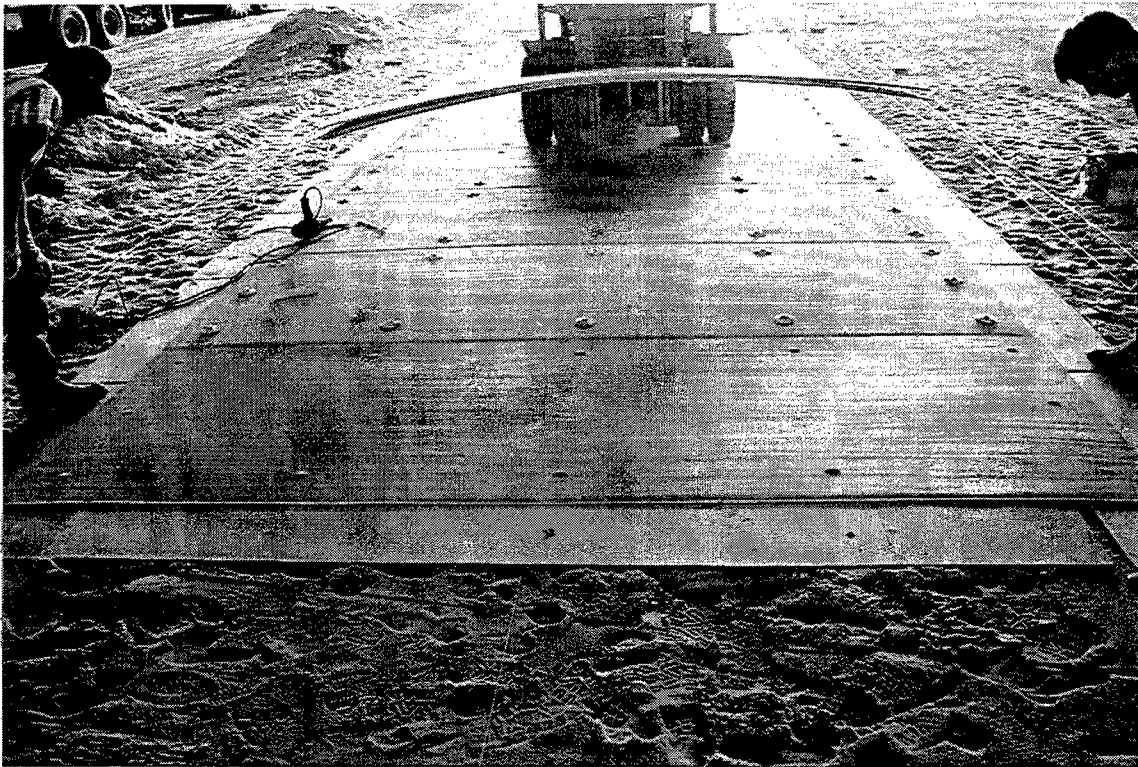


Photo 1. Fiberglass-reinforced mat

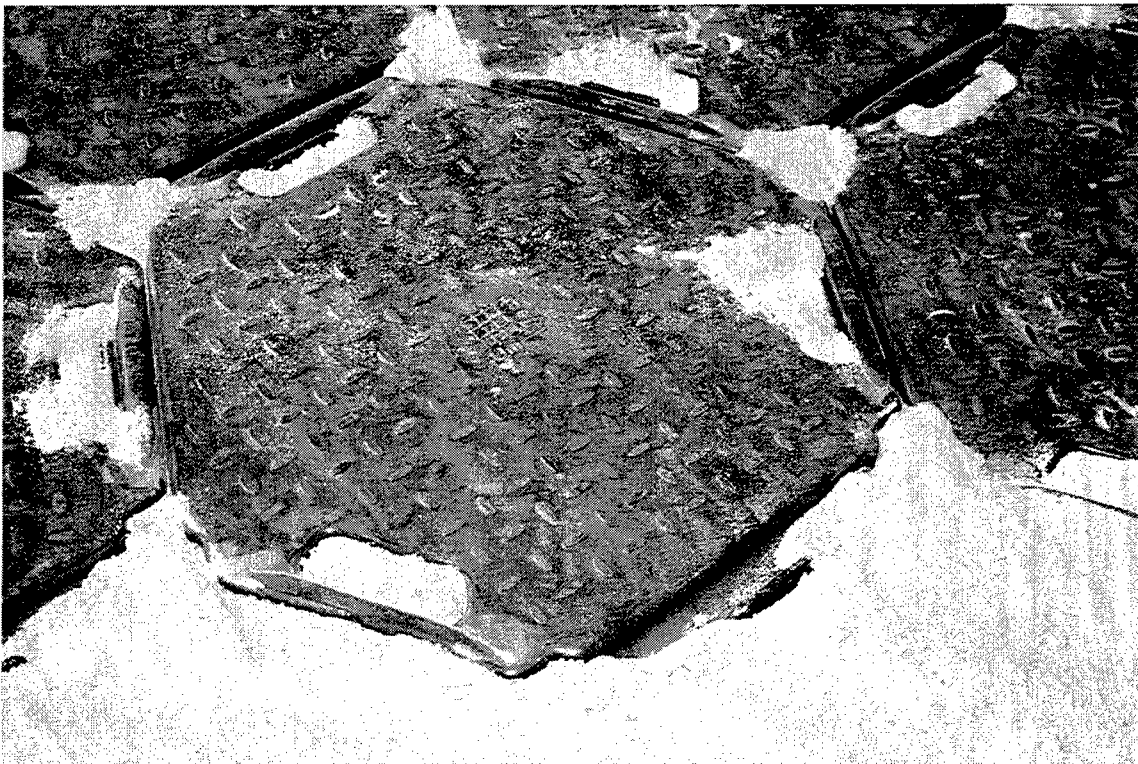


Photo 2. Plastic hexagonal mat

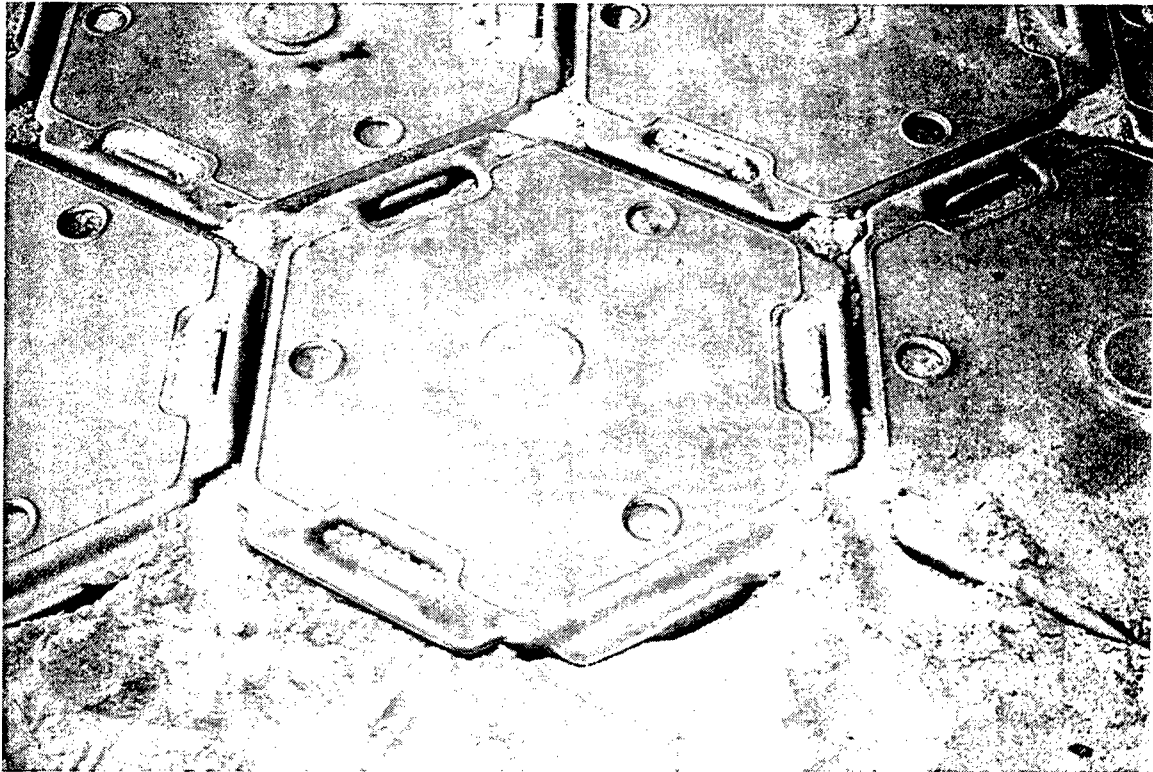


Photo 3. Aluminum hexagonal mat

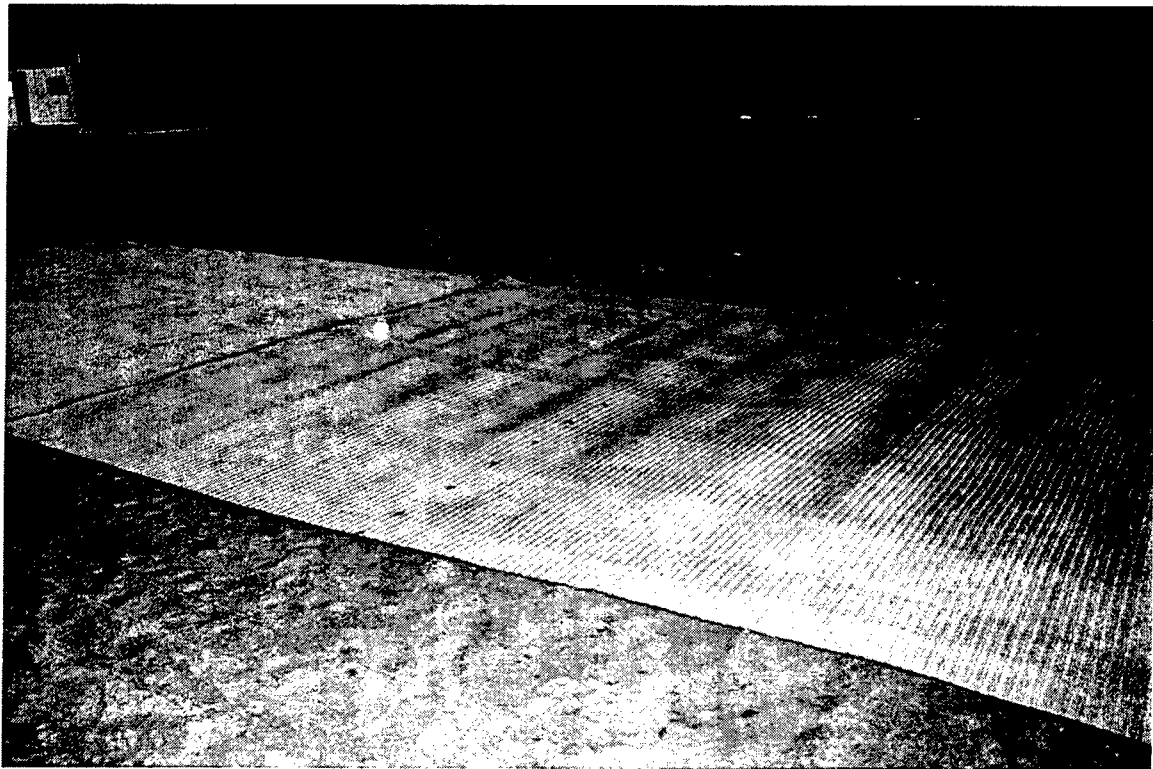


Photo 4. Unreinforced plastic mesh mat

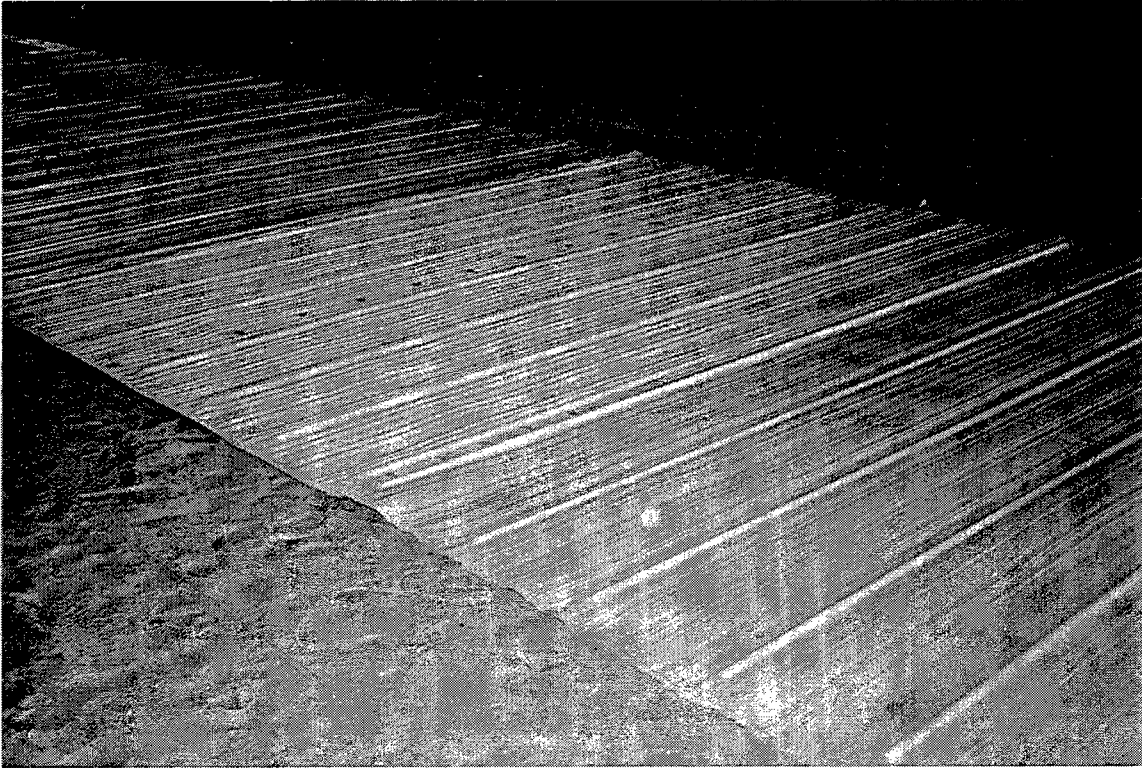


Photo 5. Reinforced plastic mesh mat

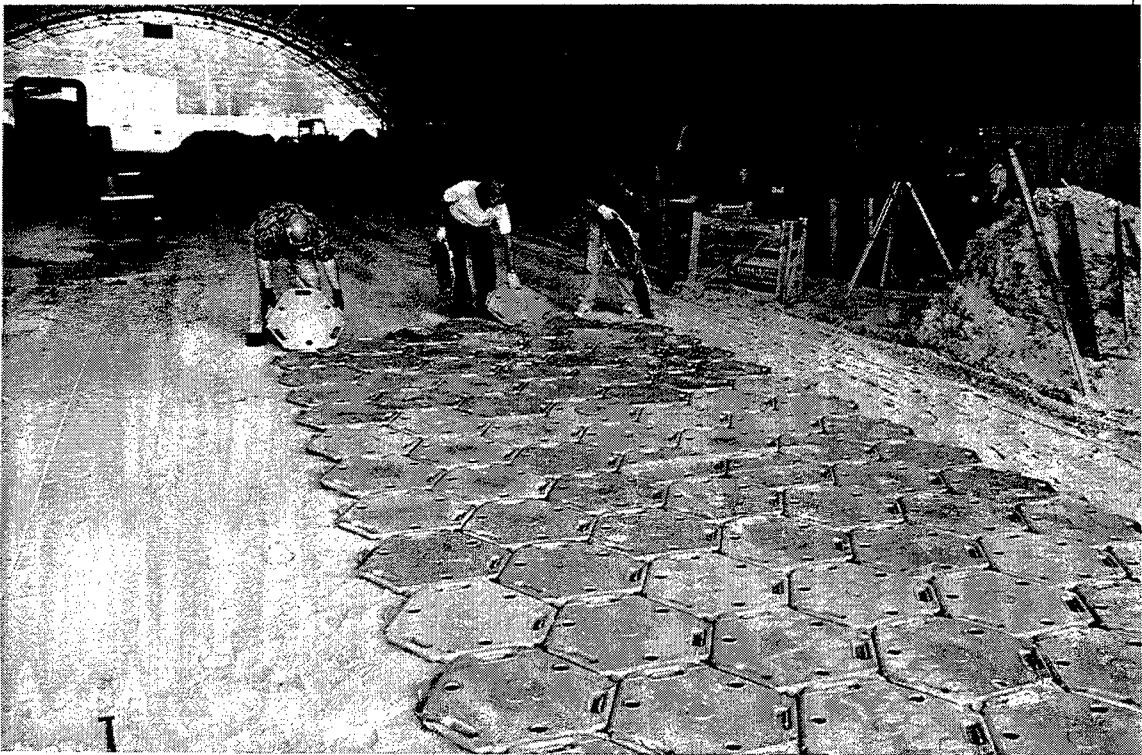


Photo 6. Roadway construction using the aluminum hexagonal mat



Photo 7. Completed hexagonal mat roadway, items 1 and 2



Photo 8. Fiberglass-reinforced mat roadway installation, item 3

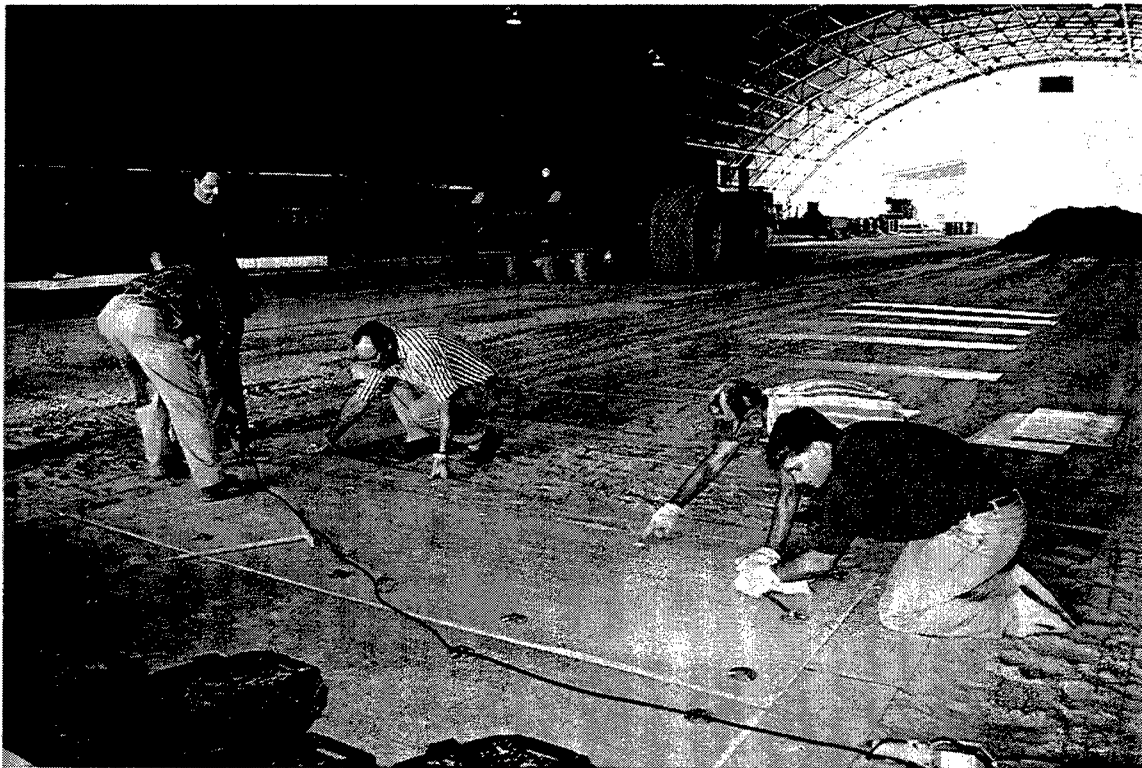


Photo 9. Connecting the fiberglass-reinforced mats



Photo 10. Tying the plastic mesh mats with 3M cable ties

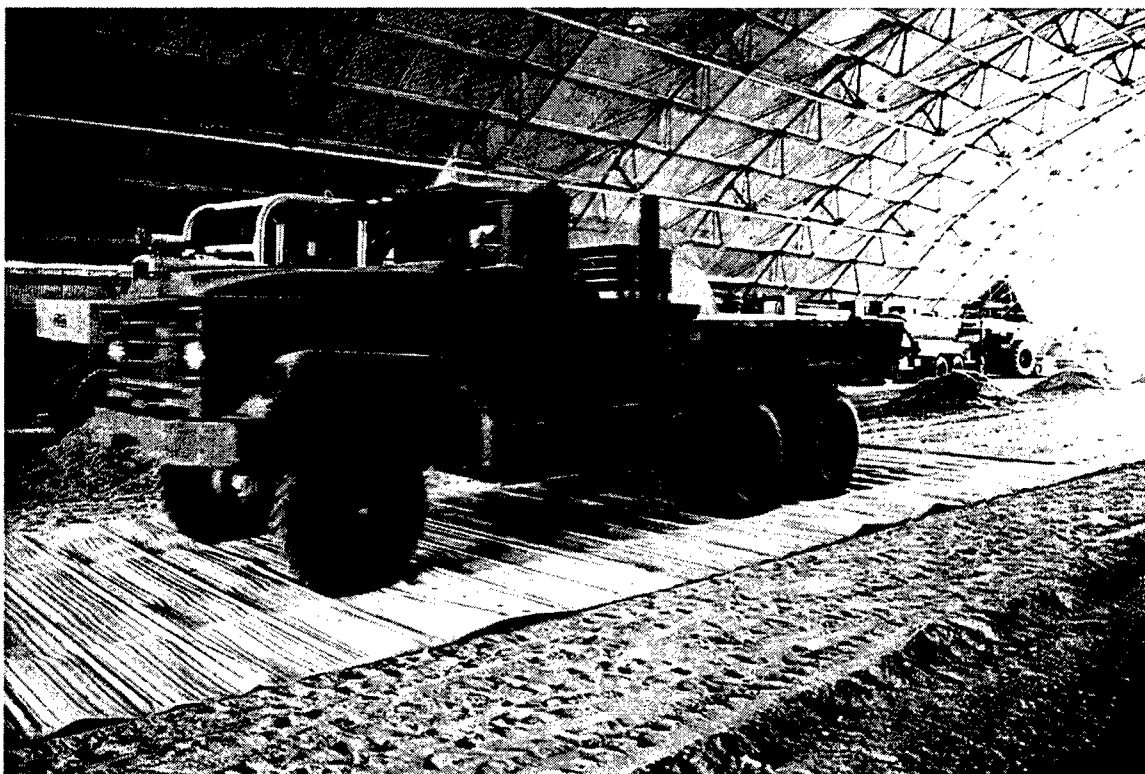


Photo 11. Completed reinforced plastic mesh mat, item 4

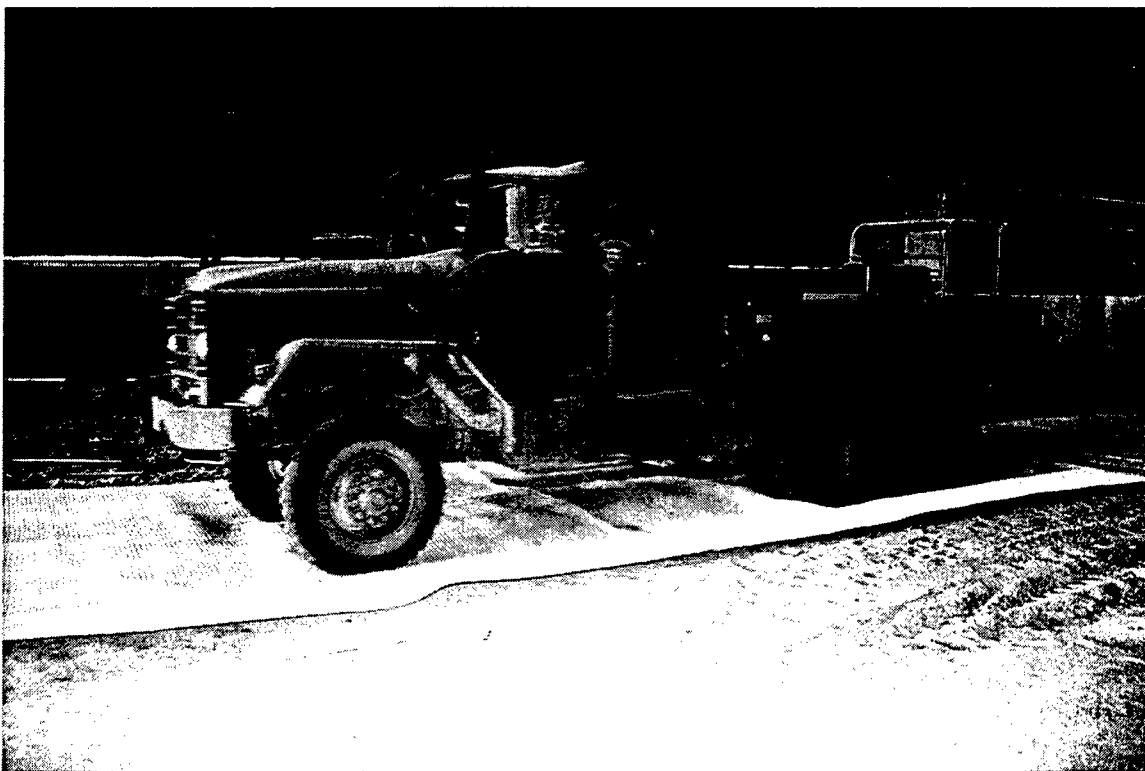


Photo 12. Completed unreinforced plastic mesh mat, item 5



Photo 13. 8-inch ruts in the control, item 6, after 25 truck passes

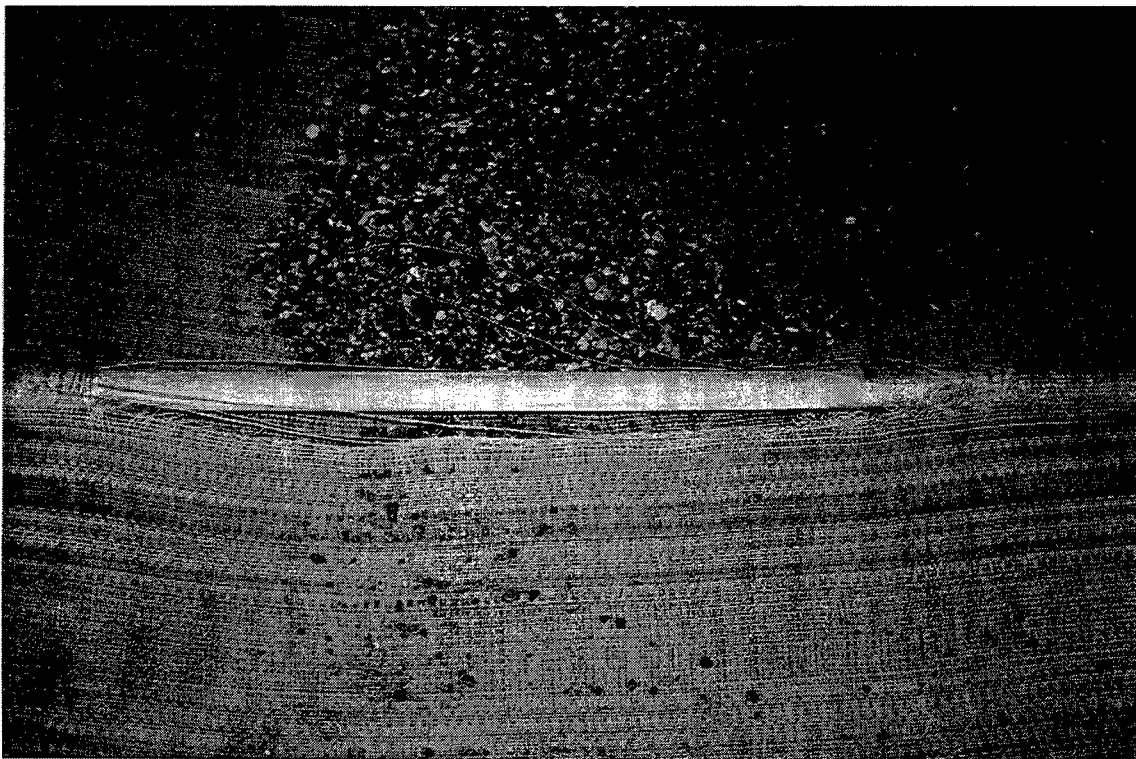


Photo 14. Tears in the reinforced plastic mesh mat, item 4

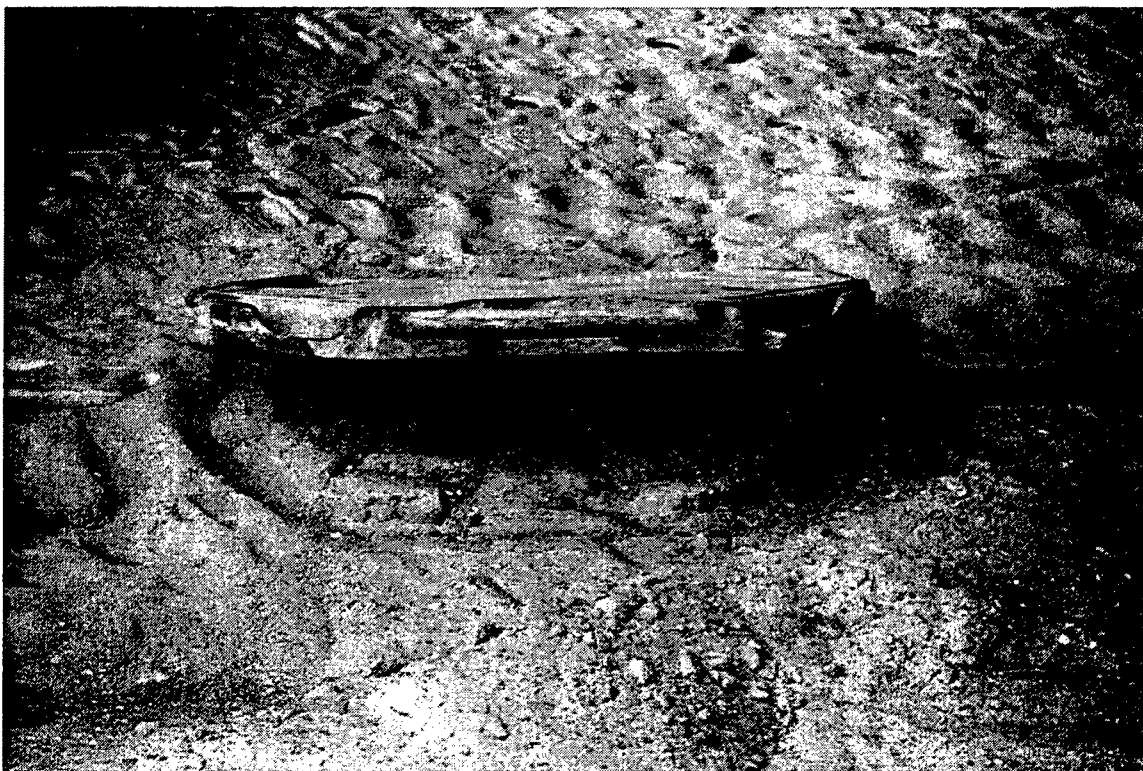


Photo 15. Edge panel tilted up during traffic, item 1



Photo 16. Post-traffic condition of items 4 and 5, after 25 truck passes

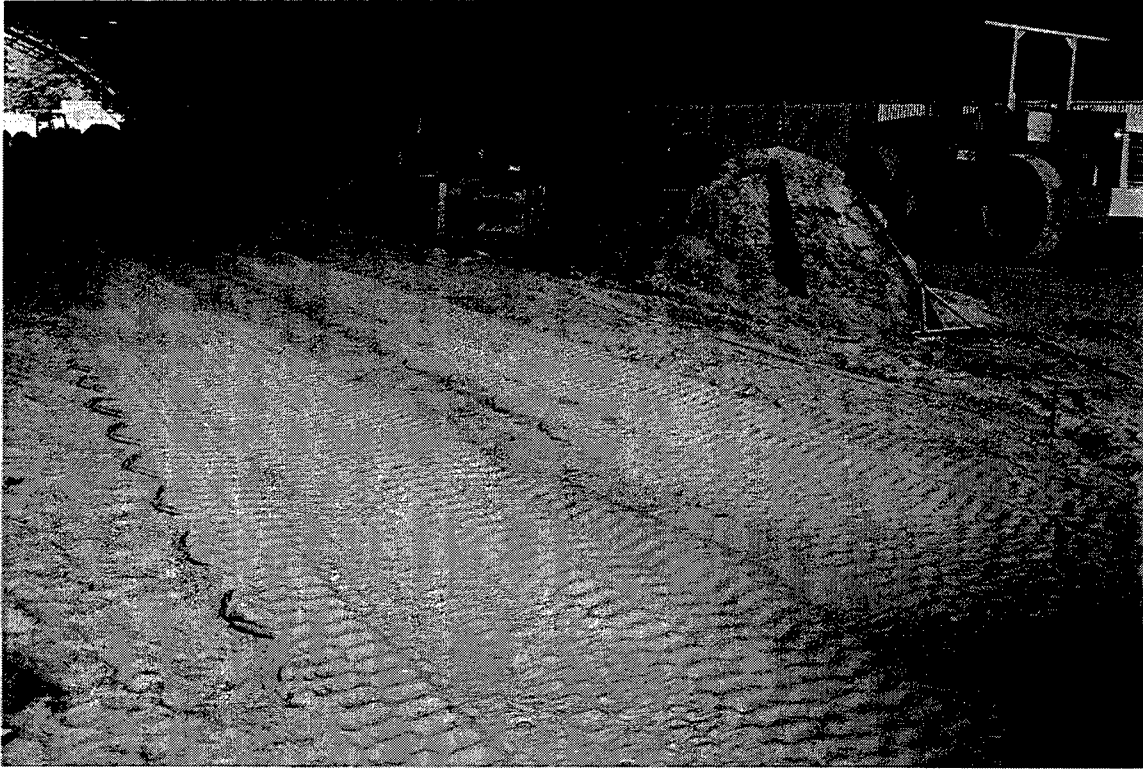


Photo 17. Post-traffic condition of item 1, after 5,000 truck passes

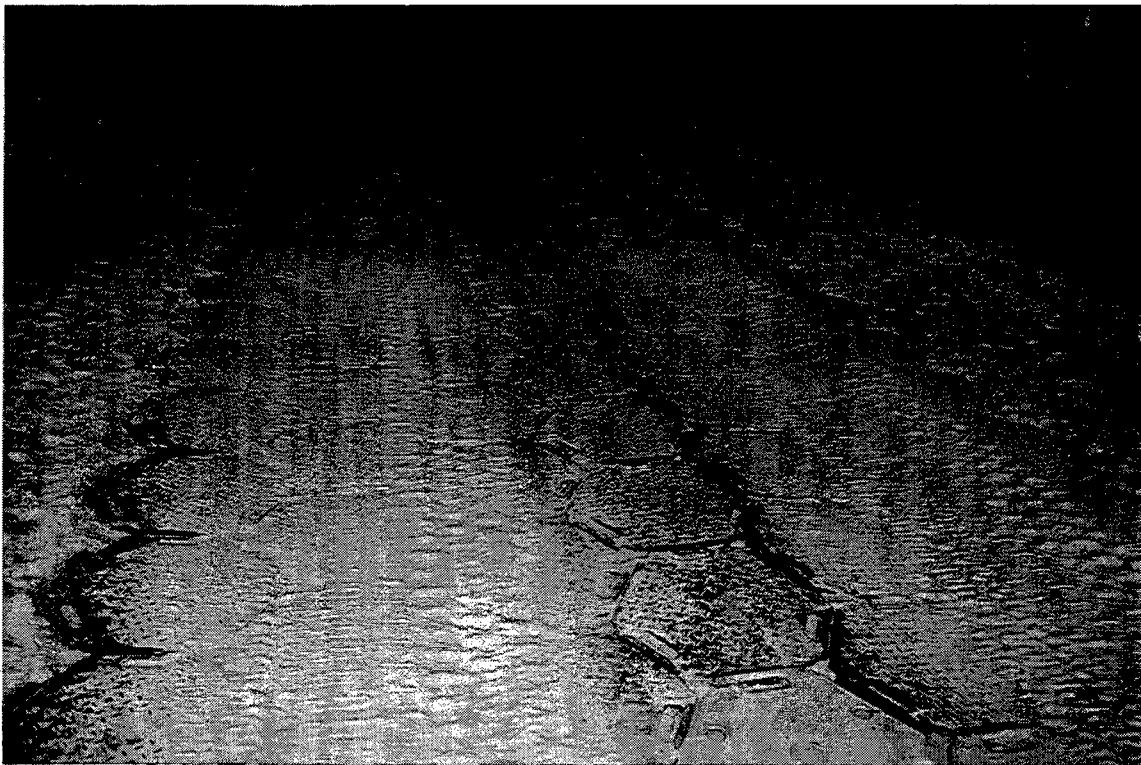


Photo 18. Post-traffic condition of item 2, after 5,000 truck passes

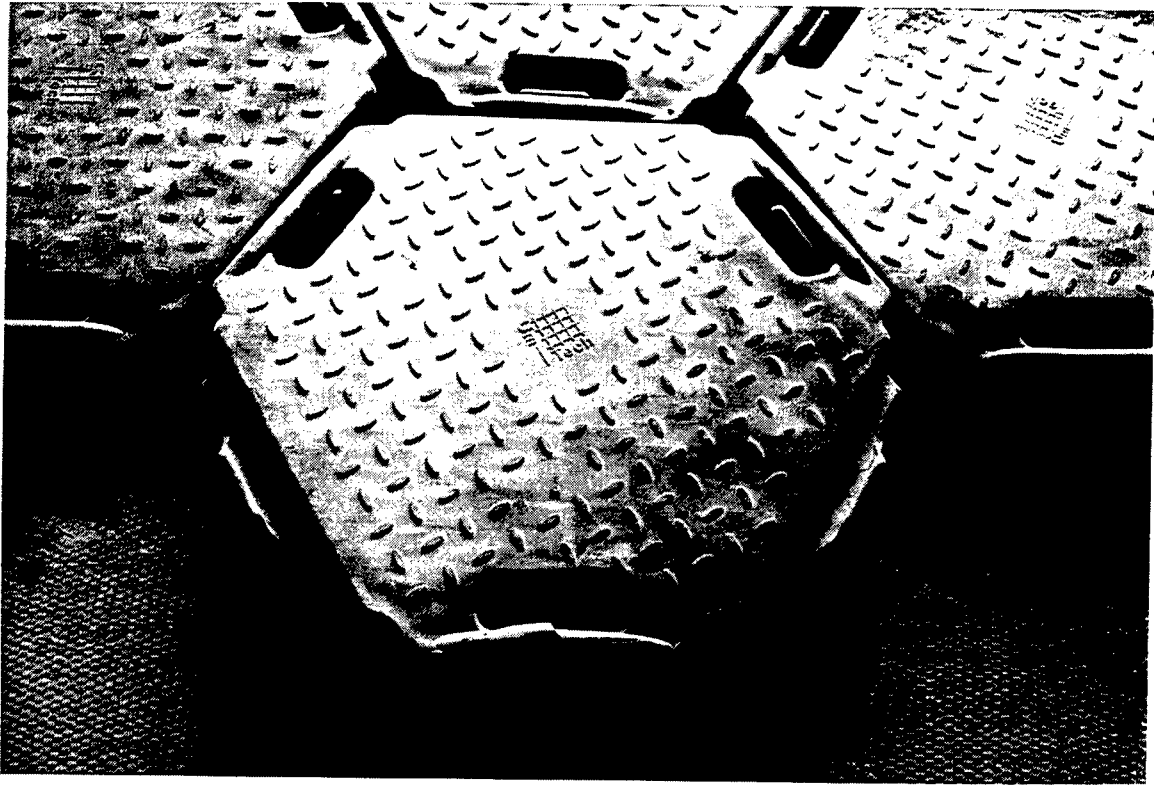


Photo 19. Broken plastic hexagonal mat panel

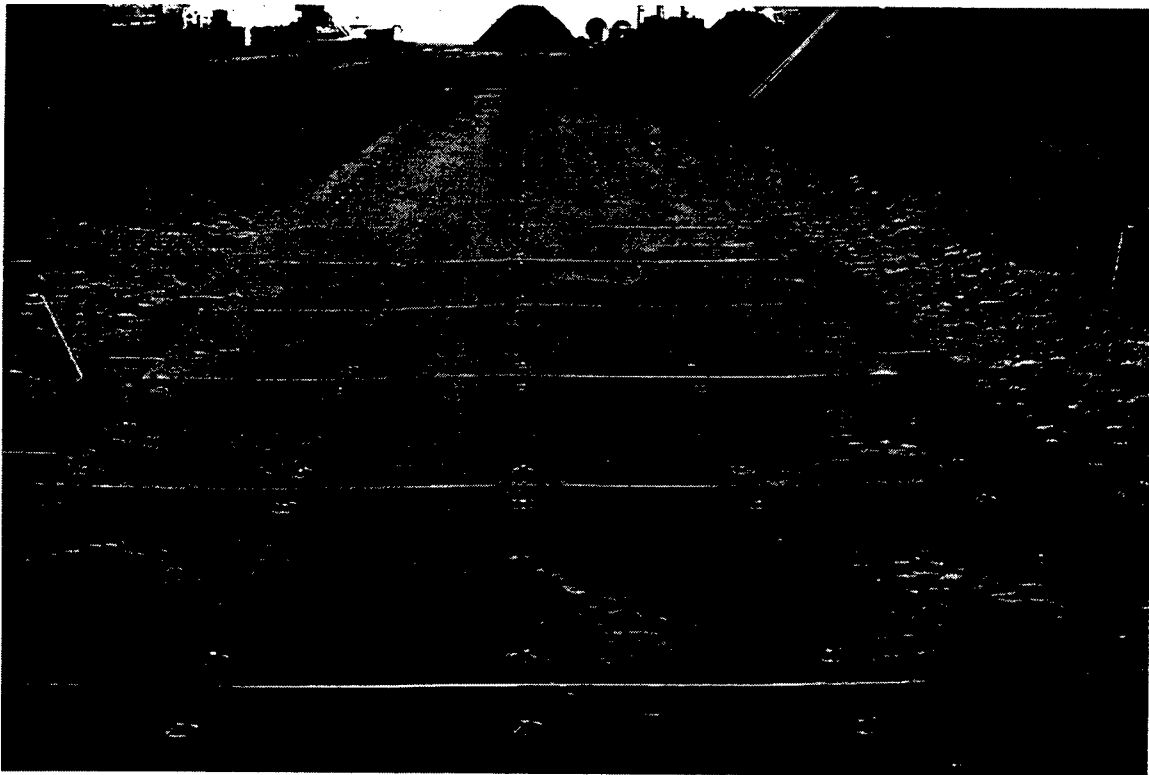


Photo 20. Post-traffic condition of item 3, after 5,000 truck passes

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